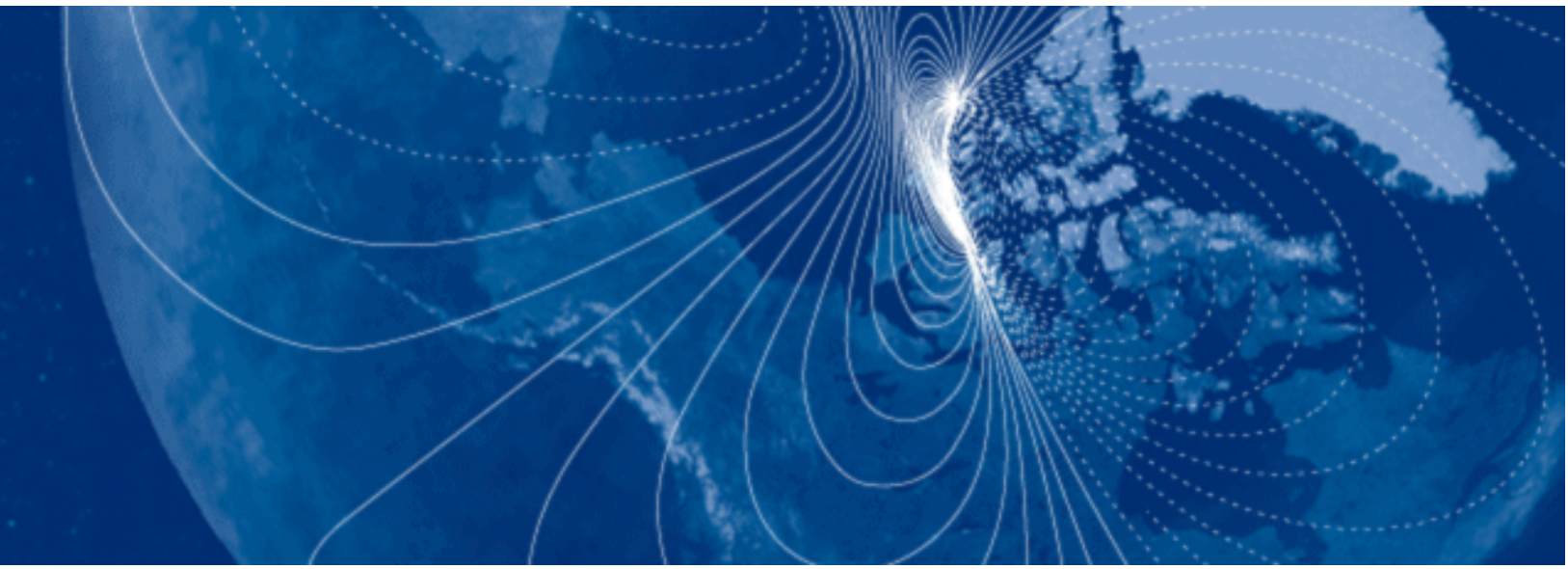

User Manual

FieldForce TCM XB

Tilt-Compensated Electronic Compass Module

PNI SENSOR CORPORATION

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1 Copyright & Warranty Information

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If any Product furnished hereunder fails to conform to the above warranty, OEM’s sole and exclusive remedy and PNI’s sole and exclusive liability will be, at PNI’s option, to repair, replace, or credit OEM’s account with an amount equal to the price paid for any such Product which fails during the applicable warranty period provided that (i) OEM promptly notifies PNI in writing that such Product is defective and furnishes an explanation of the deficiency; (ii) such Product is returned to PNI’s service facility at OEM’s risk and expense; and (iii) PNI is satisfied that claimed deficiencies exist and were not caused by accident, misuse, neglect, alteration, repair, improper installation, or improper testing. If a Product is defective, transportation charges for the return of the Product to OEM within the United States and Canada will be paid by PNI. For all other locations, the warranty excludes all costs of shipping, customs clearance, and other related charges. PNI will have a reasonable time to make repairs or to replace the Product or to credit OEM’s account. PNI warrants any such repaired or replacement Product to be free from defects in material and workmanship on the same terms as the Product originally purchased.

Except for the breach of warranty remedies set forth herein, or for personal injury, PNI shall have no liability for any indirect or speculative damages (including, but not limited to, consequential, incidental, punitive and special damages) relating to the use of or inability to use this Product, whether arising out of contract, negligence, tort, or under any warranty theory, or for infringement of any other party’s intellectual property rights, irrespective of whether PNI had advance notice of the possibility of any such damages, including, but not limited to, loss of use, revenue or profit. In no event shall PNI’s total liability for all claims regarding a Product exceed the price paid for the Product. PNI neither assumes nor authorizes any person to assume for it any other liabilities.

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2 Introduction

Thank you for purchasing PNI Sensor Corporation's TCM tilt-compensated 3-axis digital compass. The TCM is a high-performance, low-power consumption, tilt-compensated electronic compass module that incorporates PNI's advanced magnetic distortion compensation and calibration scoring algorithms to provide industry-leading heading accuracy. The TCM combines PNI Sensor Corporation's patented magneto-inductive (MI) sensors and measurement circuit technology with a 3-axis MEMS accelerometer for unparalleled cost effectiveness and performance.

PNI recognizes not all applications allow for significant tilt during calibration, so multiple calibration methods are available to ensure optimized performance can be obtained in the real world. These include Full Range Calibration, when ≥45° of tilt is possible during calibration, 2D Calibration when constrained to calibration in a horizontal or near-horizontal plane, and Limited Tilt Calibration when tilt is constrained to <45° but >5° of tilt is possible.

PNI also recognizes conditions may change over time, and to maintain superior heading accuracy it may be necessary to recalibrate the compass. So the TCM incorporates Hard Iron Only Calibration to easily account for gradual changes in the local magnetic distorting components. And the accelerometers can be recalibrated in the field if desired.

These advantages make PNI's TCM the choice for applications that require the highest accuracy and performance anywhere in the world where field calibration is limited to smaller tilt angles. Applications for the TCM include:

- Autonomous unmanned vehicles (AUVs) – underwater (UUVs), terrestrial (UGVs), and airborne (UAVs)
- Remotely operated vehicles (ROVs)
- Far target locaters and laser range finders
- Dead reckoning systems
- Systems in which the tilt angles used for calibration are physically contstrained

With its many potential applications, the TCM incorporates a flexible and adaptable command set. Many parameters are user-programmable, including reporting units, a wide range of sampling configurations, output damping, and more.

We're sure the TCM will help you to achieve the greatest performance from your system. Thank you for selecting the TCM.

3 Specifications

Table 3-1: Performance Specifications

Parameter				Value
Heading	Range			360°
	Static Accuracy	≤65° of tilt after full range calibration		<0.3° rms
		≤80° of tilt after full range calibration		<0.5° rms
		≤5° of tilt after 2D calibration		<2.0° rms
		≤2 times the calibration tilt angle when using limited-tilt calibration*		<2.0° rms
	Resolution			0.1°
	Repeatability			0.05° rms
Tilt (Pitch & Roll)	Range	Pitch		± 90°
		Roll		± 180°
	Static Accuracy	Pitch		0.2° rms
		Roll	≤65° of pitch	0.2° rms
			≤80° of pitch	0.4° rms
			≤86° of pitch	1.0° rms
	Resolution			0.01°
	Repeatability			0.05° rms
Maximum Dip Angle				85°
Magnetometers		Calibrated Field Range		± 125 µT
		Resolution		0.05 µT
		Repeatability		± 0.1 µT

*For example, if the calibration was performed over ±10° of tilt, then the TCM would provide <2° rms accuracy over ±20° of tilt.

Table 3-2: I/O Characteristics

Parameter		Value
Communication Interface		RS232, binary protocol
Communication Rate		300 to 115200 baud
Maximum Sample Rate**		≈30 samples/sec
Time to Initial Good Data*	Initial power up	<210 ms
	Sleep mode recovery	<80 ms

*FIR Taps set to 0.

**The maximum sample rate is dependent on the strength of the magnetic field, and typically will be from 25 to 32 samples/sec.

Table 3-3: Power Requirements

Parameter		Value
Supply Voltage		3.6 to 5 VDC (unregulated)
Average Current Draw	@ max. sample rate	20 mA typical
	@ 8 Hz sample rate	16 mA typical
Peak Current Draw	During application of external power	120 mA pk, 60 mA avg over 2 ms
	During logical power up/down or Sync Trigger	100 mA pk, 60 mA avg over 4 ms
Sleep Mode Current Draw		0.3 mA typical

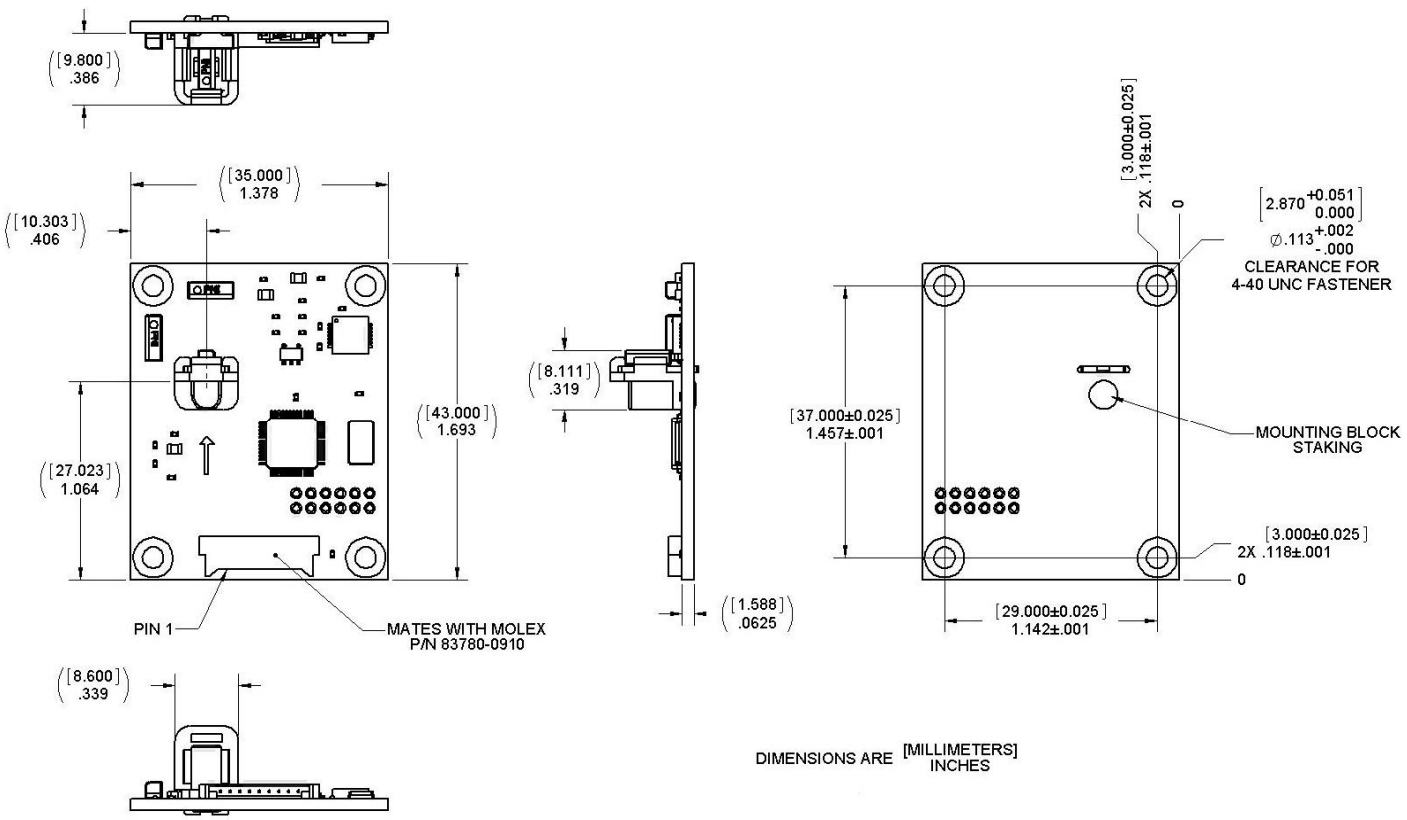
Table 3-4: Environmental Requirements

Parameter	Value
Operating Temperature*	-40C to +85C
Storage Temperature	-40C to +85C

*To meet performance specifications, recalibration may be necessary as temperature varies.

Table 3-5: Mechanical Characteristics

Parameter	Value
Dimensions (*l* x *w* x *h*)	3.5 x 4.3 x 1.3 cm
Weight	7 gm
Mounting Options	Screw mounts/Standoffs, horizontal or vertical
Connector	9-pin Molex, mates with pn 51146-0900



The default orientation for the TCM is for the silk-screened arrow to point in the “forward” direction.

Figure 3-1: TCM Mechanical Drawing

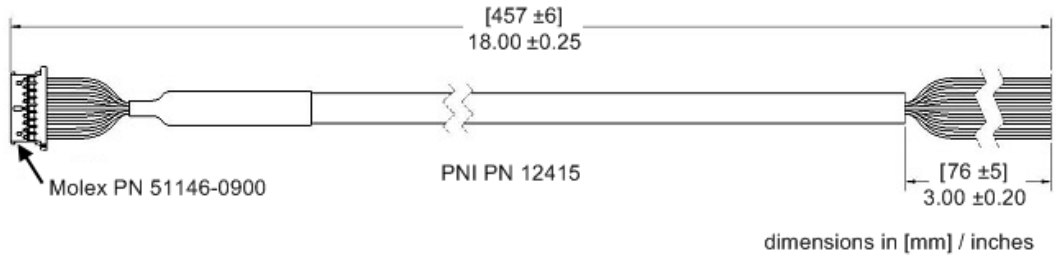


Figure 3-2: PNI Pigtailed Cable Drawing

4 Set-Up

This section describes how to configure, program, and control the TCM in your host system. To install the TCM into your system, follow these steps:

- Make electrical connections to the TCM
- Evaluate the TCM using the included TCM Studio Program
- Choose a mounting location
- Mechanically mount the TCM
- Perform user calibration

Before you install the module, it can be evaluated with the TCM Studio outside of your system. Please see Section 5.

4.1 Electrical Connections

Two optional electrical cables are available to mate the TCM to a user's host system or a PC: a 45 cm (18") custom pigtailed cable and a 1.8 m (6') custom dual-connectorized cable. Both include a Molex 51146-0900 connector on one end that mates to the TCM. The dual-connectorized cable includes a 9-pin sub-D connector on the other end to mate with a PC's serial port. This cable primarily is intended for basic evaluation of the TCM with a PC. The pigtailed cable has 9 wires accessible at the end opposite from the Molex connector, and is intended to mate with the user's host system. The Evaluation Kit includes one of each cable, while the Interface Kit includes just the pigtailed cable. Users also may supply their own cable. The pin-out of the pigtailed cable and Molex connector is given in Table 4-1. Pin 1 is indicated in *Figure 3-1*.

Table 4-1: TCM Pin Descriptions

Pin Description	Molex Connector Pin Number	Pigtailed Cable Wire Color
GND	1	Black
GND	2	Gray
GND	3	Green
NC	4	Orange
NC	5	Violet
NC	6	Brown
RS232 TxD	7	Yellow
RS232 RxD	8	Blue
+5 VDC	9	Red

4.2 Installation Location

The TCM's wide dynamic range and sophisticated calibration algorithms allow it to operate in many environments. For optimal performance however, you should mount the TCM with the following considerations in mind:

4.2.1 Operate within sensors' linear regime

The TCM can be field calibrated to correct for large static magnetic fields created by the host system. However, each axis of the TCM has a maximum calibrated dynamic range of ±125 µT: if the total field exceeds this value for any axis, the TCM may not give accurate heading information. When mounting the TCM, consider the effect of any sources of magnetic fields in the host environment that, when added to the earth's field, may take the sensors out of their linear regime. For example, large masses of ferrous metals such as transformers and vehicle chassis, large electric currents, permanent magnets such as electric motors, and so on.

4.2.2 Locate away from changing magnetic fields

It is not possible to calibrate for changing magnetic anomalies. Thus, for greatest accuracy, keep the TCM away from sources of local magnetic distortion that will change with time; such as electrical equipment that will be turned on and off, or ferrous bodies that will move. Make sure the TCM is not mounted close to cargo or payload areas that may be loaded with large sources of local magnetic fields.

4.2.3 Mount in a physically stable location

Choose a location that is isolated from excessive shock, oscillation, and vibration.

4.2.4 Preliminary testing

Testing should be performed at an early stage of development to understand and accommodate the magnetic distortion contributors in a host system. Use the data logger in TCM Studio, as discussed in Section 5.6, to perform the following tests.

Determine the distance range of field distortion. Place the compass in a fixed position, then move or energize suspect components while observing the output to determine when they are an influence.

Determine if the mounting location's magnetic field is within the l range of the compass. With the compass mounted, rotate and tilt the system in as many positions as possible. While doing so, monitor the magnetometer outputs, observing if the maximum linear range is exceeded.

4.3 Mechanical Mounting

Refer to *Figure 3-1* for TCM dimensions and the orientation of the reference frame.

The TCM is factory calibrated with respect to its mounting holes, as shown below. It must be aligned within the host system with respect to these mounting holes. Ensure any stand-offs or screws used to mount the module are non-magnetic.

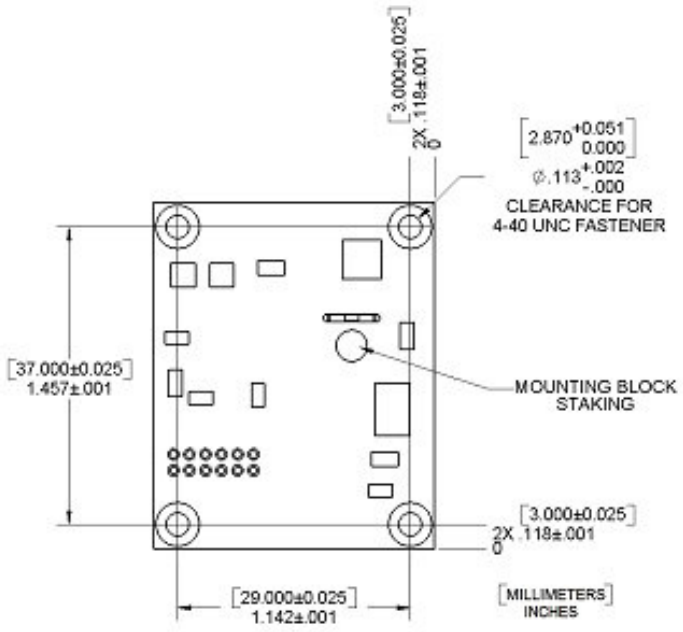
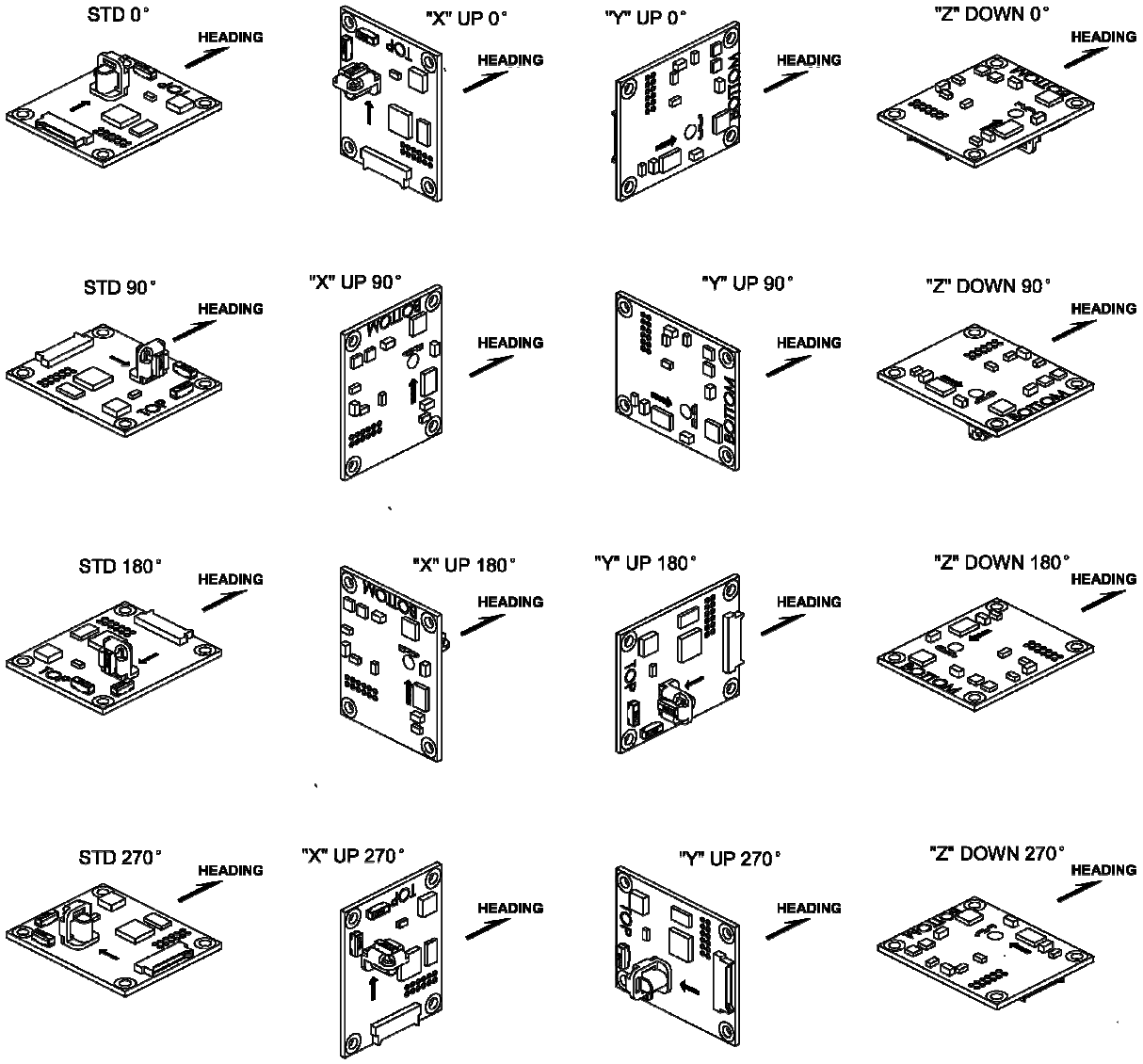


Figure 4-1: TCM Mounting Holes (bottom view)

The TCM can be mounted in various orientations. All reference points are based on the white silk-screened arrow on the top side of the board.



Note that the Z axis sensor and Molex connector are on the top surface of the module.

Figure 4-2: TCM Mounting Orientations

5 Operation with TCM Studio

The TCM Studio evaluation software communicates with the TCM through the COM port (serial port) of your PC. It puts an easy-to-use, graphical-user interface (GUI) onto the binary command language used by the TCM. Instead of manually issuing command codes, the user can use buttons, check boxes, and dialog boxes to control the TCM and obtain data. It reads the binary responses of the TCM output and formats this into labeled and easy-to-read data fields. TCM Studio also includes the ability to log and save the outputs of the TCM to a file. All of this allows you to begin understanding the capabilities of the TCM while using the TCM Studio program's friendly interface. Anything that can be performed using TCM Studio can also be performed using the RS232 interface and associated protocol. Check the PNI website for the latest TCM Studio updates at www.pnicorp.com.

Note: TCM Studio version 3.X is compatible with the TCM XB and TCM 6, but not other legacy TCM models, and legacy TCM Studio programs will not function properly with the TCM XB or TCM 6. The TCM XB model is the current version TCM with a binary communication protocol. When you launch TCM Studio, it should say "TCM Studio Ver. 3.X" in the upper left corner, where "X" is integer "0" for greater.

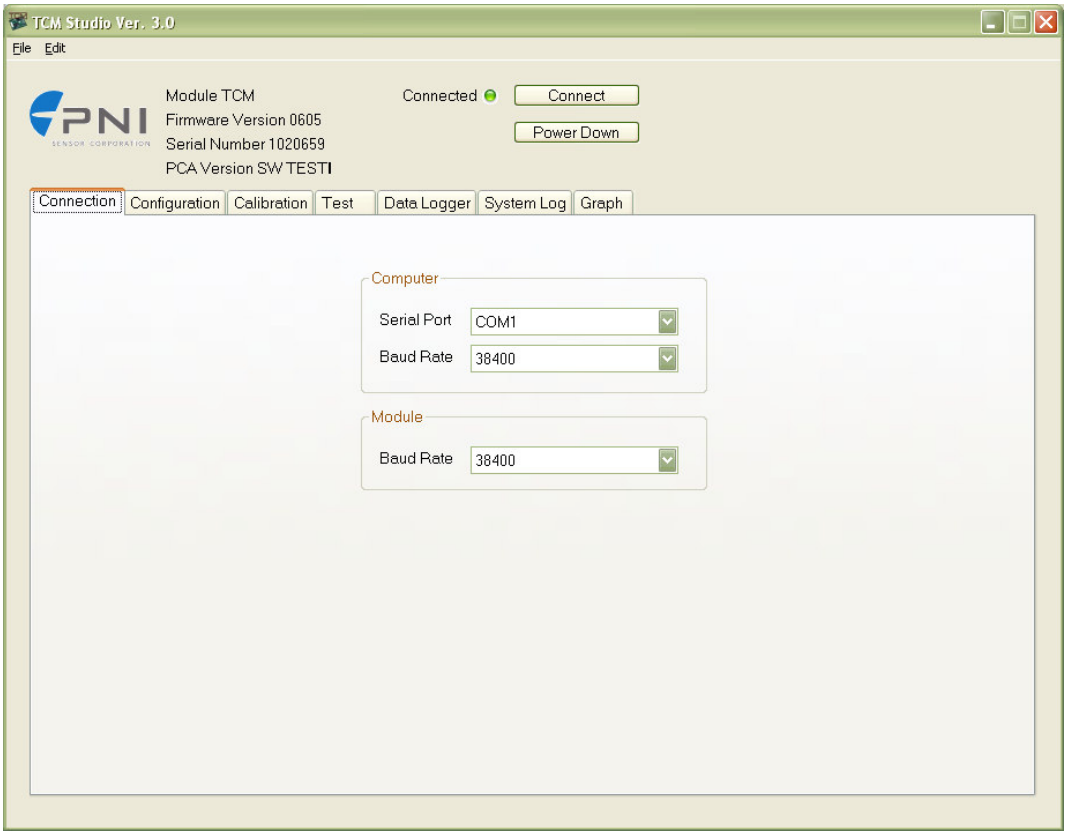
5.1 Installation onto a Windows or Mac system

TCM Studio is provided as an executable program which can be downloaded from PNI's website. It will work with Windows 98, Windows ME, Windows 2000, Windows XP, Windows Vista, and Mac OS X operating systems. Please check the PNI web page at www.pnicorp.com for the latest version.

For Windows computers, copy the TCMStudio.msi file onto your computer. Then, open the file and step through the Setup Wizard.

For Mac computers, copy the TCMStudio.zip file onto your computer. This will automatically put the application in the working directory of your computer. The Quesa plug-in, also in the .zip file, needs to be moved to: /Library/CFMSupport, if it is not already there.

5.2 Connection Tab



5.2.1 Initial connection

- If using the PNI dual-connectorized cable, ensure well-charged batteries are installed.
- Select the serial port the module is plugged into, which is generally COM 1.
- Select 38400 as the baud rate.
- Click the <Connect> button if the connection is not automatic.
- Once a connection is made the “Connected” light will turn green and the Firmware Version, Serial Number, and PCA version will be displayed in the upper left next to the PNI logo.

5.2.2 Changing baud rate

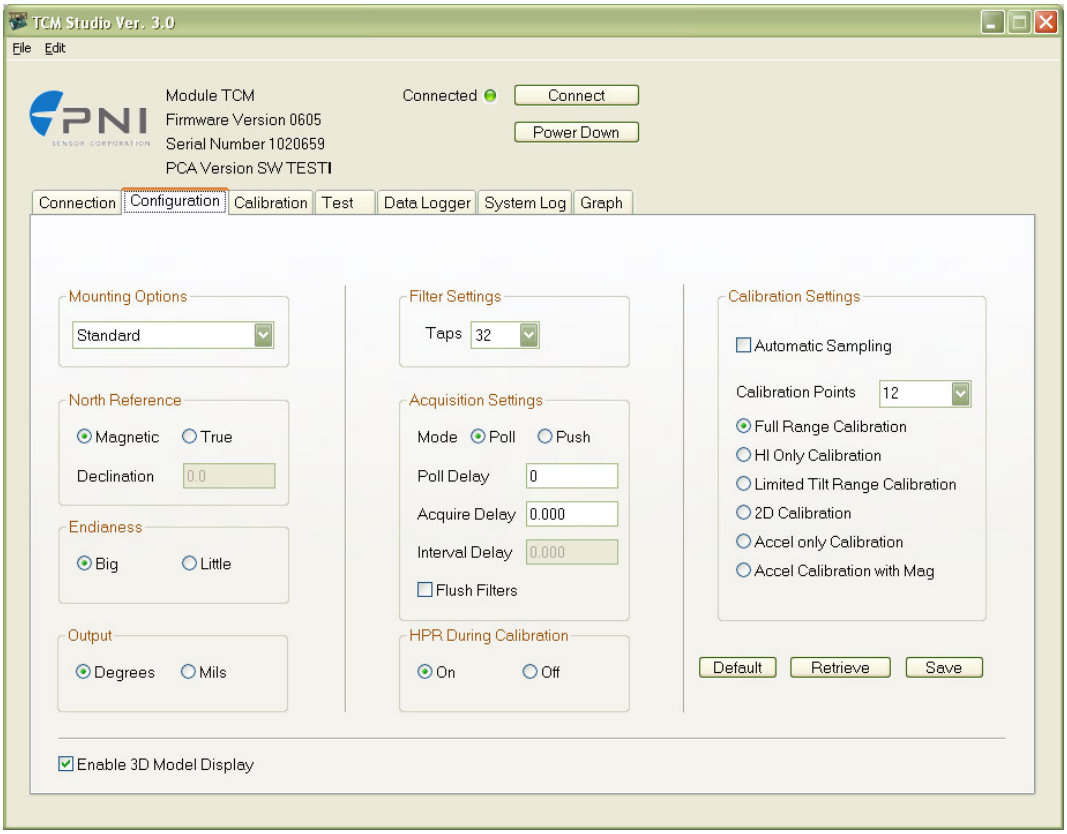
- In the Module window, select the new baud rate for the module.
- Click the <Power Down> button. The button will change to read <Power Up>.
- In the Computer window, select same baud rate for the computer.
- Click the <Power Up> button. The button will revert back to <Power Down>.

Note: While it is possible to select a baud rate of 230400, the serial port will not operate this fast.

5.2.3 Changing modules

Once a connection has been made, TCM Studio will recall the last settings. If a different module is used, click the <Connect> button once the new module is attached. This will reestablish a connection, assuming the module baud rate is unchanged.

5.3 Configuration Tab



Note: No settings will be changed in the module until the <SAVE> button has been selected.

5.3.1 Mounting Options

TCM Studio supports 16 mounting orientations, as illustrated previously in Figure 4-2. The descriptions in TCM Studio are slightly different from those shown in Figure 4-2, and the relationship between the two sets of descriptions is given below.

Table 5-1: Mounting Orientations

TCM Studio Description	Figure 4-2 Description	TCM Studio Description	Figure 4-2 Description
Standard	STD 0°	Y Sensor Up	"Y" Up 0°
Standard 90 Degrees	STD 90°	Y Sensor Up Plus 90 Degrees	"Y" Up 90°
Standard 180 Degrees	STD 180°	Y Sensor Up Plus 180 Degrees	"Y" Up 180°
Standard 270 Degrees	STD 270°	Y Sensor Up Plus 270 Degrees	"Y" Up 270°
X Sensor Up	"X" Up 0°	Z Sensor Down	"Z" Down 0°
X Sensor Up Plus 90 Degrees	"X" Up 90°	Z Sensor Down Plus 90 Degrees	"Z" Down 90°
X Sensor Up Plus 180 Degrees	"X" Up 180°	Z Sensor Down Plus 180 Degrees	"Z" Down 180°
X Sensor Up Plus 270 Degrees	"X" Up 270°	Z Sensor Up Plus 270 Degrees	"Z" Down 270°

5.3.2 North Reference

Magnetic

When the <Magnetic> button is selected, heading will be relative to magnetic north.

True

When the <True> button is selected, heading will be relative to true north. In this case, the declination needs to be set in the "Declination" window. Refer to Section 6.3 for more information.

5.3.3 Endianess

Select either the <Big> or <Little> Endian button. The default setting is <Big>. See Sections 7.2 and 7.3 for additional information.

5.3.4 Output

The TCM module can output heading, pitch, and roll in either degrees or mils. Click either the <Degrees> or <Mils> button. The default is <Degrees>. (There are 6400 mils in a circle, such that 1 degree = 17.7778 mils and 1 mil = 0.05625 degree.)

5.3.5 Enable 3D Model

TCM Studio's Test tab includes a live-action 3-D rendering of a helicopter. Some computer systems may not have the graphics capability to render the 3D Model, for this reason it may be necessary to turn off this feature.

5.3.6 Filter Setting (Taps)

The TCM incorporates a finite impulse response (FIR) filter to effectively provide a more stable heading reading. The number of taps (or samples) represents the amount of filtering to be performed. The user should select either 0, 4, 8, 16, or 32 taps, with zero taps representing no filtering. Note that selecting a larger number of taps can significantly slow the time for the initial sample reading and, if "Flush Filters" is selected, the rate at which data is output. The default setting is 32.

5.3.7 Acquisition Settings

Mode

- "Poll" mode should be selected when the host system will poll the TCM for data. TCM Studio allows the user to simulate this on their PC. In this case, TCM Studio requests data from the TCM module at a relatively fixed basis.
- "Push" mode should be selected if the user will have the TCM output data at a relatively fixed rate to the host system. In this case the TCM module is pushing data out to TCM Studio at a relatively fixed rate.

Poll Delay

The Poll Delay is relevant when Poll Mode is selected, and is the time delay, in seconds, between the completion of TCM Studio receiving one set of sampled data and requesting the next sample set. If the time is set to "0", then TCM Studio requests new data as soon as the previous request has been fulfilled. Note that the inverse of the Poll Delay is somewhat greater than the sample rate, since the Poll Delay does not include actual acquisition time.

Interval Delay

The Interval Delay is relevant when Push Mode is selected, and is the time delay, in seconds, between completion of the TCM module sending one set of sampled data and the start of sending the next sample set. If the time is set to 0 then the TCM will begin sending new data as soon as the previous data set has been sent. Note that the inverse of the Interval Delay is somewhat greater than the sample rate, since the Interval Delay does not include actual acquisition time.

Acquire Delay

The Acquire Delay sets the time between samples taken by the module, in seconds. This is an internal setting that is NOT tied to the time with which the module transmits data to TCM Studio or the host system. Generally speaking, the Acquire Delay is either set to 0, in which case the TCM is constantly sampling or set to equal either the Poll Delay or Interval Delay values. The advantage of running

with an Acquire Delay of 0 is that the FIR filter can run with a relatively high Tap value to provide stable and timely data. The advantage of using a greater Acquire Delay is that power consumption can be reduced, assuming the Interval or Poll Delay are no less than the Acquire Delay.

Flush Filters

The filtering is set to only update the filter with the last sample taken, for example once the initial 32 samples are taken (assuming Taps is set to the default value of 32) any new sample is added to the end with the first sample being dropped. In the case where the "Acquire Time" is set to a value it would be prudent to set the module to flush the filter prior to calculating the heading. This flushing will require the module to take 32 new samples to use for the calculation.

Note: If the "Flush Filters" checkbox is checked, it will take longer for the module to output updated data.

5.3.8 HPR During Calibration

When the <On> button is selected, heading, pitch, and roll will be output on the Calibration tab during a calibration.

5.3.9 Calibration Settings

Automatic Sampling

When selected the module will take a point once the minimum change requirement and the stability check, if selected, has been satisfied. If the user wants to have more control over when the point will be taken then Auto Sampling should be deselected. Once deselected, the <Take Sample> button on the Calibration tab will be active. Selecting the <Take Sample> button will indicate to the module to take a sample once the minimum requirements are met.

Calibration Points

The user can select the number of points to take during a calibration. The minimum number of points needed for an initial calibration is 10, although a hard-iron only (re)calibration can be performed with only 4 samples. The module will need to be rotated through at least 180 degrees in the horizontal plane with a minimum of at least 1 positive and 1 negative Pitch and at least 1 positive and 1 negative Roll as part of the 12 points.

Calibration Method Buttons

- **Full Range Calibration** - recommended calibration method when >45° of tilt is possible. The minimum recommended number of calibration points is 12.
- **Hard Iron Only Calibration** - serves as a hard iron recalibration to a prior calibration. If the hard iron distortion around the module has changed, this calibration can bring the module back into specification. The minimum recommended number of calibration points is 6.

- **Limited Tilt Range Calibration** - recommended calibration method when >5° of tilt calibration is available, but tilt is restricted to <45°. (i.e. full range calibration is not possible.) The minimum recommended number of calibration points is 12.
- **2D Calibration** - recommended when the available tilt range is limited to ≤5°. The minimum recommended number of calibration points is 12.
- **Accel Calibration Only** – The user should select this when accelerometer calibration will be performed. The minimum recommended number of calibration points is 18.
- **Accel Calibration w/Mag** – The user should select this when magnetometer and accelerometer calibration will be performed simultaneously. The minimum recommended number of calibration points is 18.

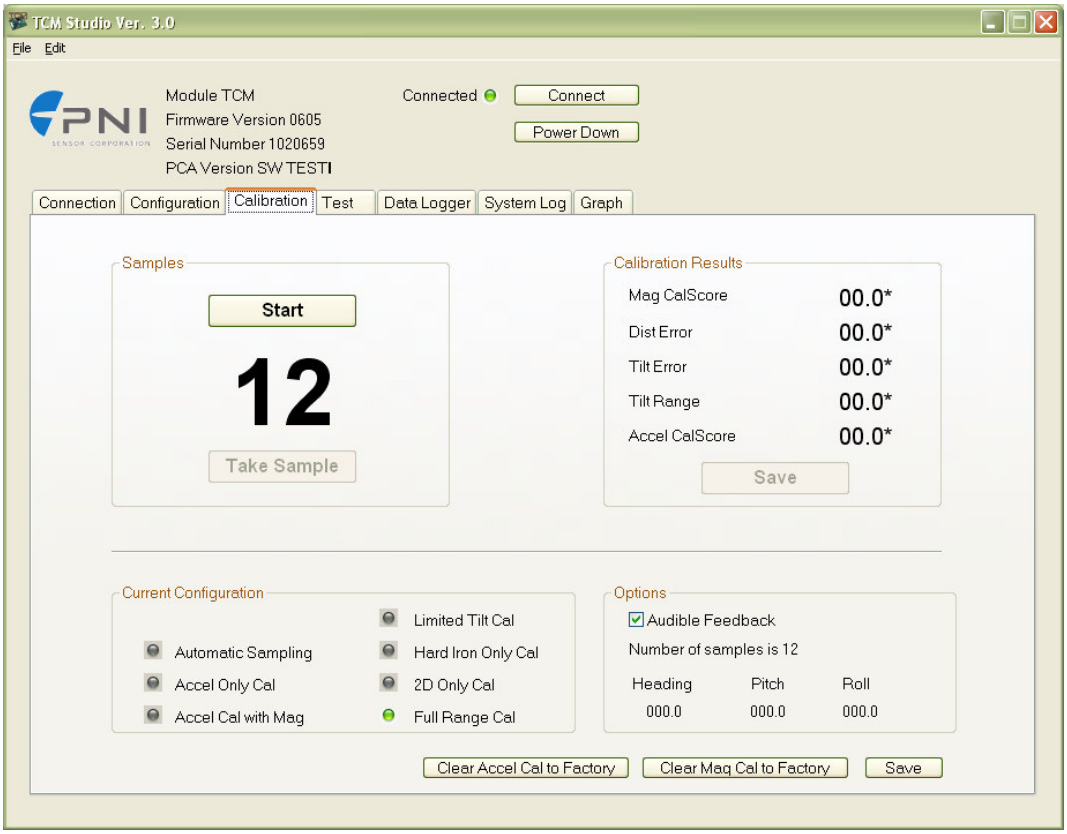
5.3.10 Default

Clicking this button reverts TCM Studio program to the factory default settings.

5.3.11 Retrieve

Clicking on this button causes TCM Studio to read the settings from the module and display them on the screen.

5.4 Calibration Tab



Note: The default settings of the module are recommended for the highest accuracy and quality of calibration.

5.4.1 Samples

Before proceeding, refer to Section 6.2 for the recommended calibration procedure corresponding to the calibration method selected on the Configuration tab.

Clicking the <Start> button begins the calibration process.

If “Automatic Sampling” is not checked on the Configuration tab, it is necessary to click the <Take Sample> button to take a calibration sample point. This should be repeated until the total number of samples (as set on the Configuration tab) is taken, changing the orientation of the module between samples as discussed in Section 6.2.

If “Automatic Sampling” is checked, the module will need to be held steady for a short time and then a sample automatically will be taken. Once the window indicates the next number, the module’s orientation should be changed and held steady for the next

sample. Once the pre-set number of samples has been taken (as set on the Configuration tab) the calibration is complete.

5.4.2 Calibration Results

Once the calibration is complete the "Calibration Results" window will indicate the quality of the calibration. This may take a few seconds. The primary purpose of these scores is to demonstrate that the field calibration was successful, as demonstrated by a low CalScore. The other parameters provide information that may assist in improving the CalScore should it be unacceptably high.

Mag CalScore
Represents the over-riding indicator of the quality of the magnetometer calibration. Acceptable scores will be <1 for Full Range Calibration, <2 for other methods. Note that it is possible to get acceptable scores for Dist Error and Tilt Error and still have a rather high Mag CalScore value. The most likely reason for this is the TCM is close to a source of local magnetic distortion that is not fixed with respect to the module.

Dist Error
Indicates the quality of the sample point distribution, primarily looking for an even yaw distribution. Significant clumping or a lack of sample points in a particular section can result in a poor score. The score should be <1 and close to 0.

Tilt Error
Indicates the contribution to the CalScore caused by tilt or lack thereof, and takes into account the calibration method. The score should be <1 and close to 0.

Tilt Range
This reports the larger of either half the full pitch range or half the full roll range of sample points. For example, if the module is pitched +10° to -20º, and rolled +25º to -15º, the Tilt Range value would be 20º (as derived from [+25º - {-15º}]/2). For Full Range Calibration and Hard Iron Only Calibration, this should be ≥45°. For 2D Calibration, this ideally should be ≈2°. For Limited Tilt Range Calibration the value should be as large a possible given the user's constraints.

Accel CalScore
Represents the over-riding indicator of the quality of the accelerometer calibration. Acceptable scores will be <1.

If either CalScore is too high, click the <Start> button to begin a new calibration. If the calibration is acceptable, then click the <Save> button in the "Calibration Results" window to save the calibration to the module's flash. If this button is not selected then the module will need to be recalibrated after a power cycle.

Note: If a calibration is aborted, all the score's will read "179.80", and the calibration coefficients will not be changed. (Clicking the <Save> button will not change the calibration coefficients either.)

5.4.3 Current Configuration

These indicators mimic the pertinent selections made on the Configuration tab.

5.4.4 Options

This window indicates how many samples are to be taken and provides real time heading, pitch, and roll information if "HPR During Calibration" is set to <On>, both as defined on the Configuration tab.

Audible Feedback:

If selected TCM Studio will give an audible signal once a calibration point has been taken. Note that an audible signal also will occur when the <Start> button is clicked, but no data will be taken.

5.4.5 Clear

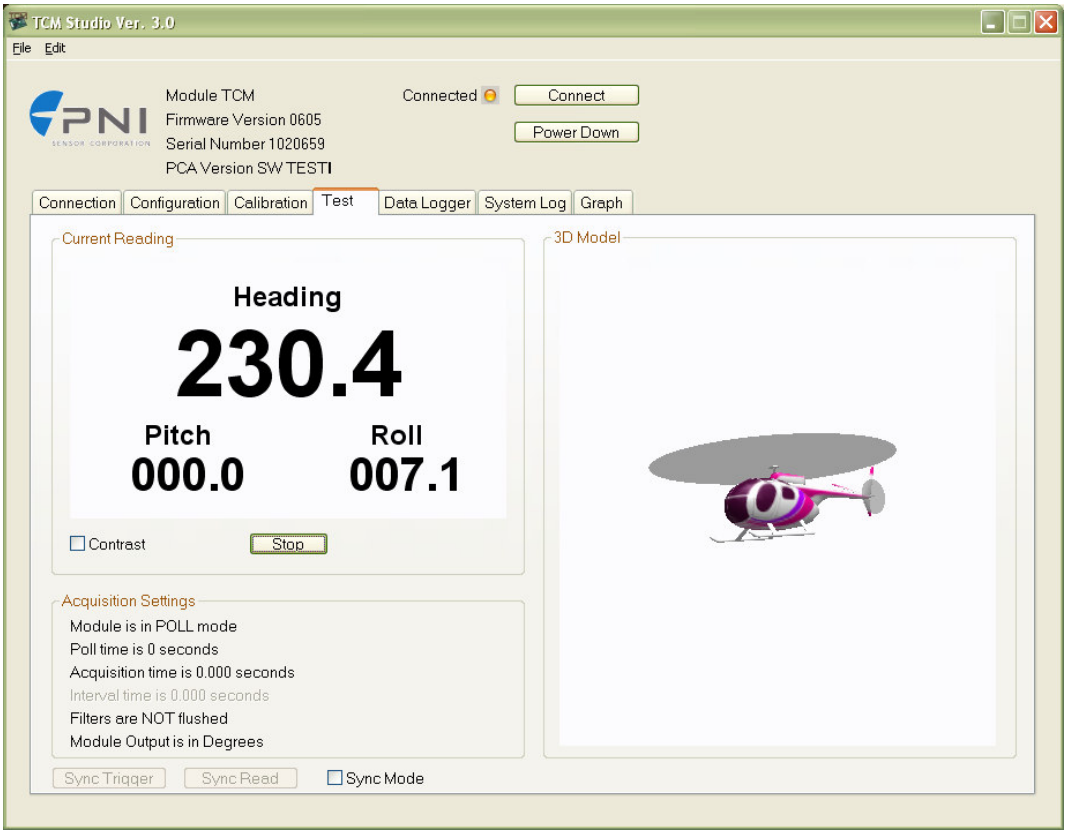
Clear Mag Cal to Factory:

This button clears the user's calibration of the magnetometers. Once selected, the module reverts to its factory magnetometer calibration. To save this action in nonvolatile memory, click the <Save> button. It is not necessary to clear the current calibration in order to perform a new calibration.

Clear Accel Cal to Factory:

This button clears the user's calibration of the accelerometers. Once selected, the module reverts back to its factory accelerometer calibration. To save this action in non-volatile memory, click the <Save> button. It is not necessary to clear the current calibration in order to perform a new calibration.

5.5 Test Tab



5.5.1 Current Reading

Once the <Go> button is selected the module will begin outputting heading, pitch and roll information. Selecting the <Stop> button or changing tabs will halt the output of the module.

Contrast:

Selecting this box sets the “Current Readings” window to have yellow lettering on a black background, rather than black lettering on a white background.

5.5.2 3D Model

The helicopter will follow the movement of the TCM and give a visual representation of the module’s orientation, assuming the “Enable 3D Model Display” box is selected on the Configuration tab.

5.5.3 Acquisition Settings

These indicators mimic the pertinent selections made on the Configuration tab.

5.5.4 Sync Mode

Sync Mode enables the module to stay in sleep mode until the user's system sends a trigger to report data. When so triggered, the TCM will wake up, report data once, then return to sleep mode. One application of this is to lower power consumption. Another use of the Sync Mode is to trigger a reading during an interval when local magnetic sources are well understood. For instance, if a system has considerable magnetic noise due to nearby motors, the Synch Mode can be used to take measurements when the motors are turned off.

Enter Sync Mode:

On the Test tab, above the tabs and 3D model, click the "Sync Mode" check box to enter Sync Mode.

Sync Mode Output:

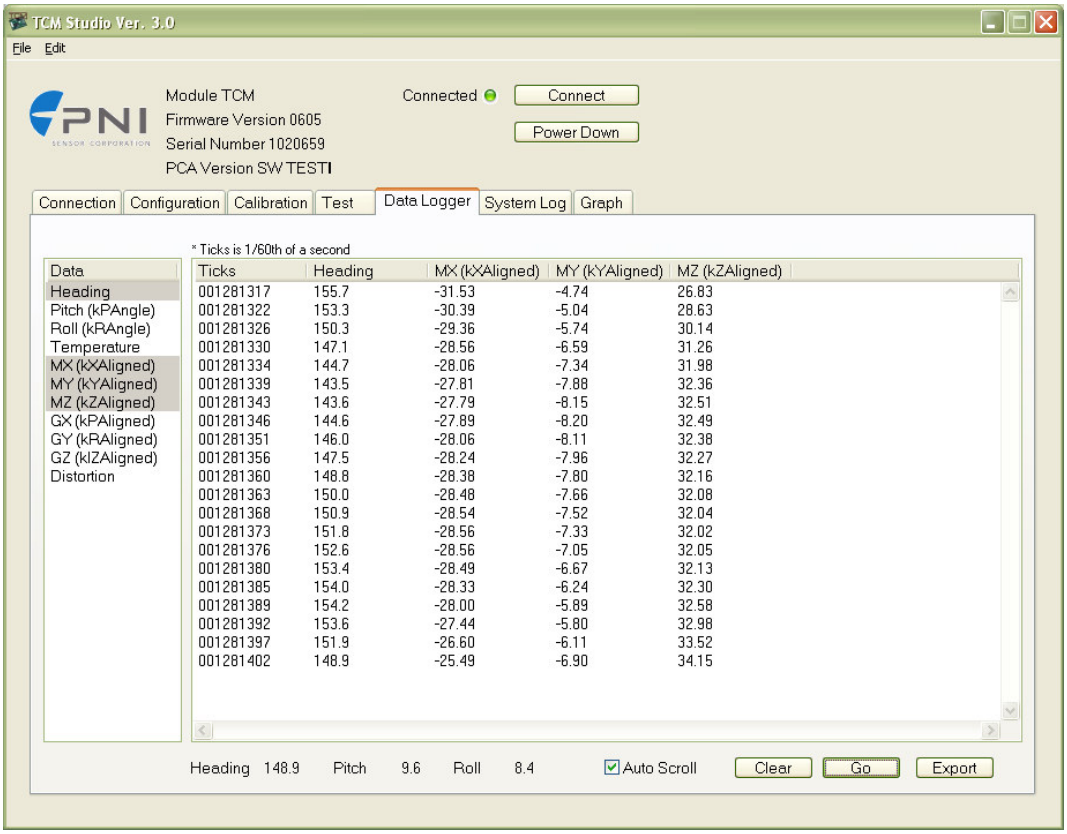
To retrieve the first reading, click the <Sync Read> button. Heading, pitch and roll information will be displayed on Current Reading window. If the "Enable 3D Model Display" box is selected on the Configuration tab, then the helicopter will follow the movement as well. The module will enter sleep mode after outputting the heading, pitch, and roll information. To obtain subsequent readings, the user should first click on the <Sync Trigger> button to wake up the module and then click on the <Sync Read> button to get the readings, after which the module will return to sleep.

Exit Sync Mode:

Click on the <Sync Trigger> button and then uncheck the "Sync Mode" check box to exit Sync Mode.

Note that <Sync Trigger> sends a 0xFF signal as an external interrupt to wake up the module. This is not done for the first reading as the module is already awake.

5.6 Data Logger Tab

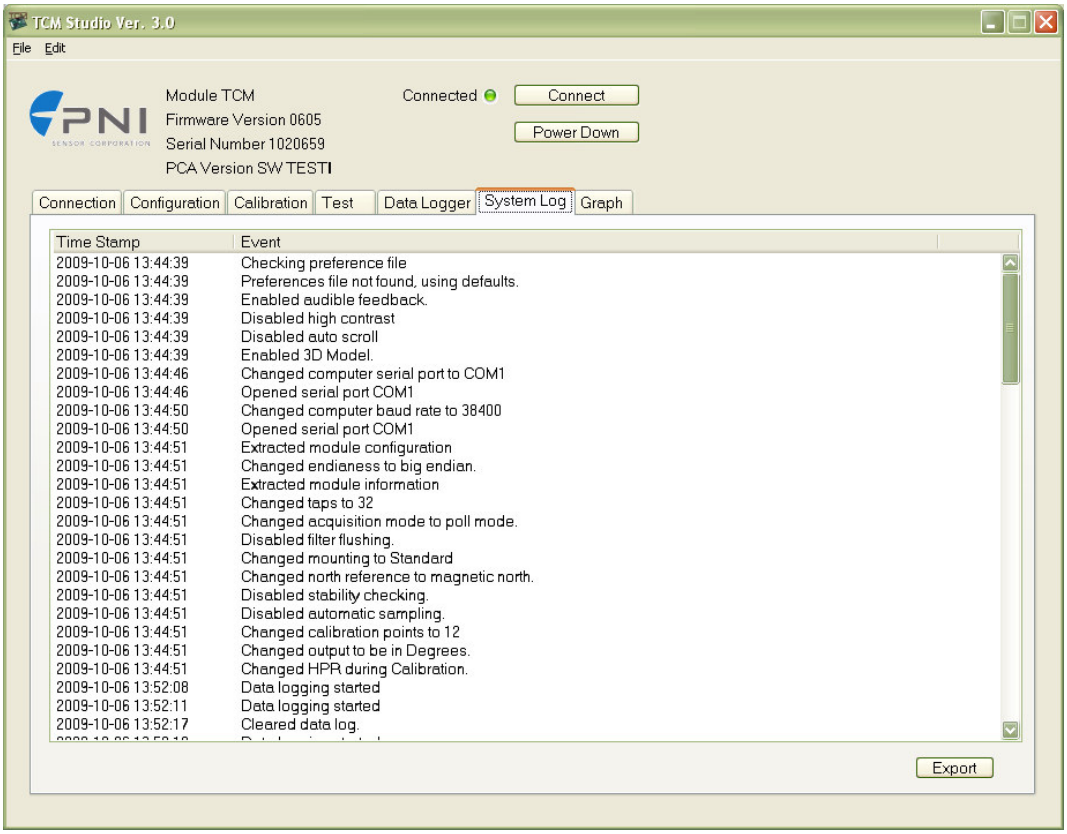


TCM Studio can capture measurement data and then export it to a text file. To acquire data and export it, follow the procedure below:

- Select the parameters you wish to log in the “Data” window. Use Shift-Ctrl-Click and Ctrl-Click to select multiple items. (In the screen shot above, “Heading”, “MX (kXAligned)”, “MY (kYAligned)”, and “MZ (kZAligned)” were selected.)
- Click the <Go> button to start logging. The <Go> button changes to a <Stop> button after data logging begins.
- Click the <Stop> button to stop logging data.
- Click the <Export> button to save the data to a file.
- Click the <Clear> button to clear the data from the window.

Note: The data logger use ticks for time reference. A tick is 1/60 second.

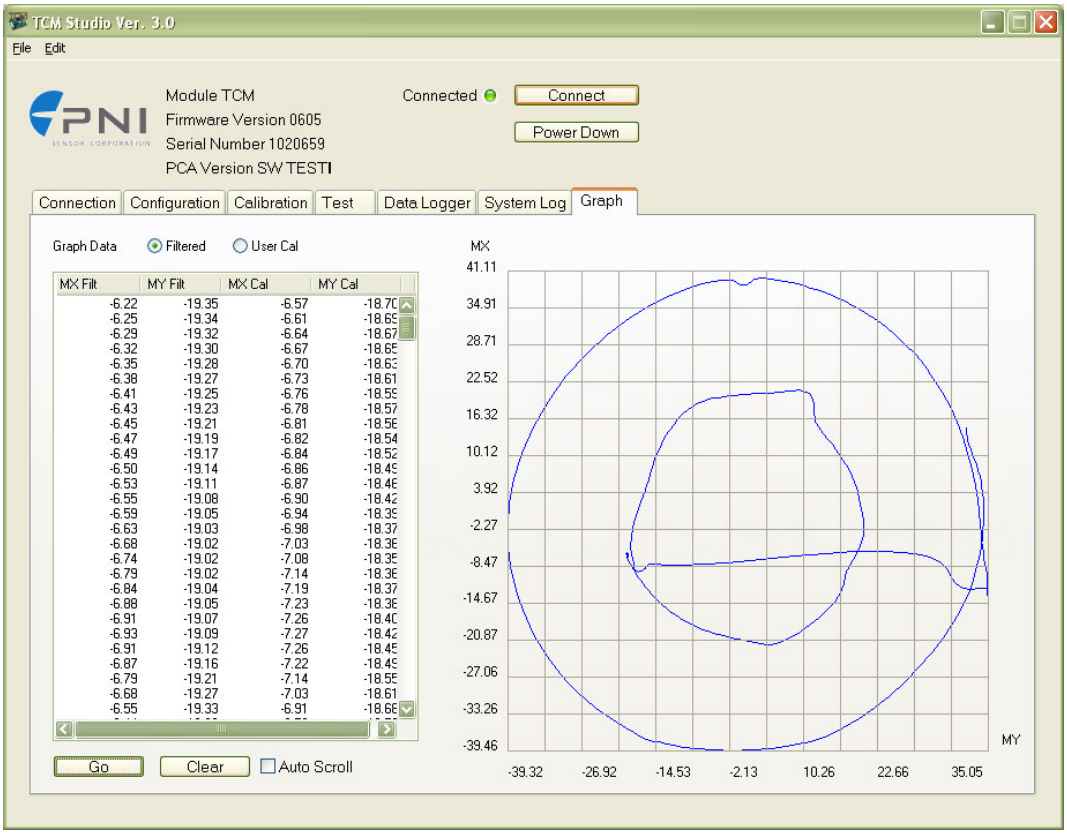
5.7 System Log Tab



The System Log tab shows all communication between TCM Studio and the TCM module since TCM Studio was opened. Closing TCM Studio will erase the system log.

Select the <Export> button, at the bottom right of the screen, to save the system log to a text file.

5.8 Graph Tab



The graph provides a 2-axis (X,Y) plot of the measured field strength. The graph can be used to visually see hard and soft iron effects within the environment measured by the TCM module as well as corrected output after a user calibration has been performed. (The screen shot shows the MX and MY readings as the module was held horizontally and rotated through 360º in the horizontal plane, then held in a vertical orientation and rotated 360º in the vertical plane.)

6 User Calibration

Sources of magnetic distortion positioned near the TCM will distort Earth's local magnetic field and should be compensated for in the host system. Examples of such sources include ferrous metals and alloys (ex. iron, nickel, non-stainless steel, etc.), batteries, audio speakers, current-carrying wires, and electric motors. Compensation is accomplished by calibrating the module while mounted in the user's system. In the user's system it is expected the sources of magnetic distortion will remain fixed relative to the module's position. By performing a user calibration, the TCM identifies the local sources of magnetic distortion and negates their effects from the overall reading to provide an accurate compass heading.

Additionally, the TCM's MEMS accelerometers gradually may change over time, and it may be desirable to recalibrate the accelerometers from time-to-time. The accelerometer calibration procedure corrects for changes in accelerometer gain and offset. Unlike the magnetometers, the accelerometers may be calibrated outside the host system. Accelerometer calibration is more sensitive to noise or hand jitter than magnetometer calibration, especially for subsequent use at high tilt angles. Because of this, a stabilized fixture is recommended for accelerometer calibration, although resting the unit against a stable surface often is sufficient. Alternatively, the TCM can be returned to PNI for accelerometer recalibration.

Key Points

1. Accelerometer calibration requires the TCM essentially be rotated through a full sphere of coverage. However, it does not require the module be incorporated into the user's system during the calibration.
2. Magnetometer calibration requires incorporating the module into the user's system such that the magnetic components of the user's system can be compensated for.
3. Magnetometer and accelerometer calibrations can be performed simultaneously. But it may be easier to perform them separately since the requirements of each calibration are significantly different. (Magnetometer calibration requires the module be incorporated in the user's system, while accelerometer calibration requires full sphere coverage.)
4. Full Range (magnetometer) Calibration provides the highest heading accuracy, but often performing a Full Range Calibration is not practical. 2D and Limited Tilt Calibration allow for reasonably good calibration when the range of allowable motion is limited. Hard Iron Only Calibration relatively easily updates the hard-iron compensation coefficients.

5. The number of calibration sample points and calibration pattern is dependent on the calibration method, and these are discussed in Section 6.2.
6. Pay attention to the calibration scores. See Section 5.4.2 for the score meanings.

6.1 Magnetic Field Calibration Theory

The main objective of a magnetometer calibration is to compensate for distortions to the magnetic field caused by the host system. To that end the TCM needs to be mounted within the host system and the entire host system needs to be moved as a single unit during the calibration. The TCM allows the user to perform a calibration only in a 2D plane (2D Calibration Method) or with limited tilt, but provides the greatest accuracy if the user can rotate through 360° of yaw and ±45° of tilt,

6.1.1 Hard and Soft Iron Effects

Hard iron distortions are caused by permanent magnets and magnetized steel or iron objects within close proximity to the sensors. This type of distortion remains constant and in a fixed location relative to the sensors for all heading orientations. Hard-iron distortions add a constant magnitude field component along each axis of sensor output.

Soft-iron distortions are the result of interactions between the Earth's magnetic field and any magnetically "soft" material within close proximity to the sensors. In technical terms, soft materials have a high permeability. The permeability of a given material is a measure of how well it serves as a path for magnetic lines of force, relative to air, which has an assigned permeability of one. Unlike hard-iron distortion, soft-iron distortion changes as the host system's orientation changes, making it more difficult to compensate.

The TCM 3-axis digital compass features both soft-iron and hard-iron correction.

6.1.2 Pitch and Roll

The TCM uses MEMS accelerometers to measure the tilt angle of the compass. This data is output as pitch and roll data, and is also used in conjunction with the magnetometers to provide a tilt-compensated heading reading.

The TCM utilizes Euler angles as the method for determining accurate orientation. This method is the same used in aircraft orientation where the outputs are Heading (Yaw), Pitch and Roll. When using Euler angles, roll is defined as the angle rotated around an axis through the center of the fuselage while pitch is rotation around an axis through the center of the wings. These two rotations are independent of each other since the rotation axes rotate with the plane body.

For the TCM a positive pitch is when the front edge of the board is rotated upward and a positive roll is when the right edge of the board is rotated downward.

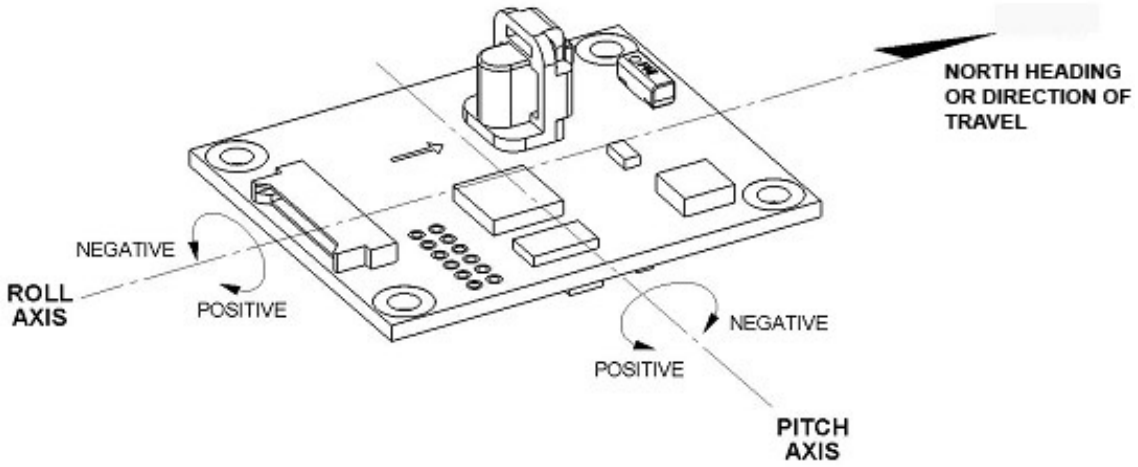


Figure 6-1: Positive & Negative Roll and Pitch Definition

6.2 Calibration Procedures

These procedures provide instructions for performing a user calibration of the TCM module using TCM Studio and the TCM connectorized cable. All TCM Studio application functions are available in the TCM's RS232 interface allowing this procedure to be translated into a user's embedded solution. This calibration sequence demonstrates a good distribution of the recommended minimum sample points, additional points may be added.

With the TCM module connected and communicating with TCM Studio, go to the Configuration tab and configure as follows:

- In the Filter Settings window set Taps to 32
- Calibration Settings: Uncheck the Automatic Sampling box
- Choose the appropriate Calibration Method
- Set Calibration Points to at least 12 for Full Range Calibration, Limited Tilt Range Calibration and 2D Calibration; at least 6 for Hard Iron Only Calibration; and at least 18 for Accel Only Calibration and Accel and Mag Calibration.
- Click the <Save> button.
- Go to the Calibration tab.

6.2.1 Full Range Calibration with 12 Sample Points

This calibration procedure is appropriate when the module can be tilted ±45° or more. The Full Range Calibration option calibrates out hard and soft iron effects in three dimensions, and allows for the highest accuracy readings. The recommended calibration pattern is a series of 3 circles of evenly spaced points, with as much tilt variation as expected during use. PNI recommends using 12 to 32 calibration points for a Full Range Calibration, although 10 calibration points is acceptable but less likely to yield good results.

Move the module to the following positions noting that these are not absolute heading directs but rather approximate heading changes referenced to your first heading sample. You do not need to know actual true or magnetic north.

Note: Once you begin taking calibration points, pausing between desired calibration points will cause unintentional points to be taken with auto sampling enabled. PNI recommends enabling the audible feedback feature to reduce the chance of unknowingly taking unintentional samples.

Module with slight pitch (-5° to +5°)

0° yaw with 10°-20° positive roll (initial starting position)
90° yaw with 10°-20° negative roll
180° yaw with 10°-20° positive roll
270° yaw with 10°-20° negative roll

Module with large positive pitch (>+45°)

30° with 10°-20° positive roll
120° with 10°-20° negative roll
210° with 10°-20° positive roll
300° with 10°-20° negative roll

Module with large negative pitch (<-45°)

60° with 10°-20° positive roll
150° with 10°-20° negative roll
240° with 10°-20° positive roll
330° with 10°-20° negative roll.

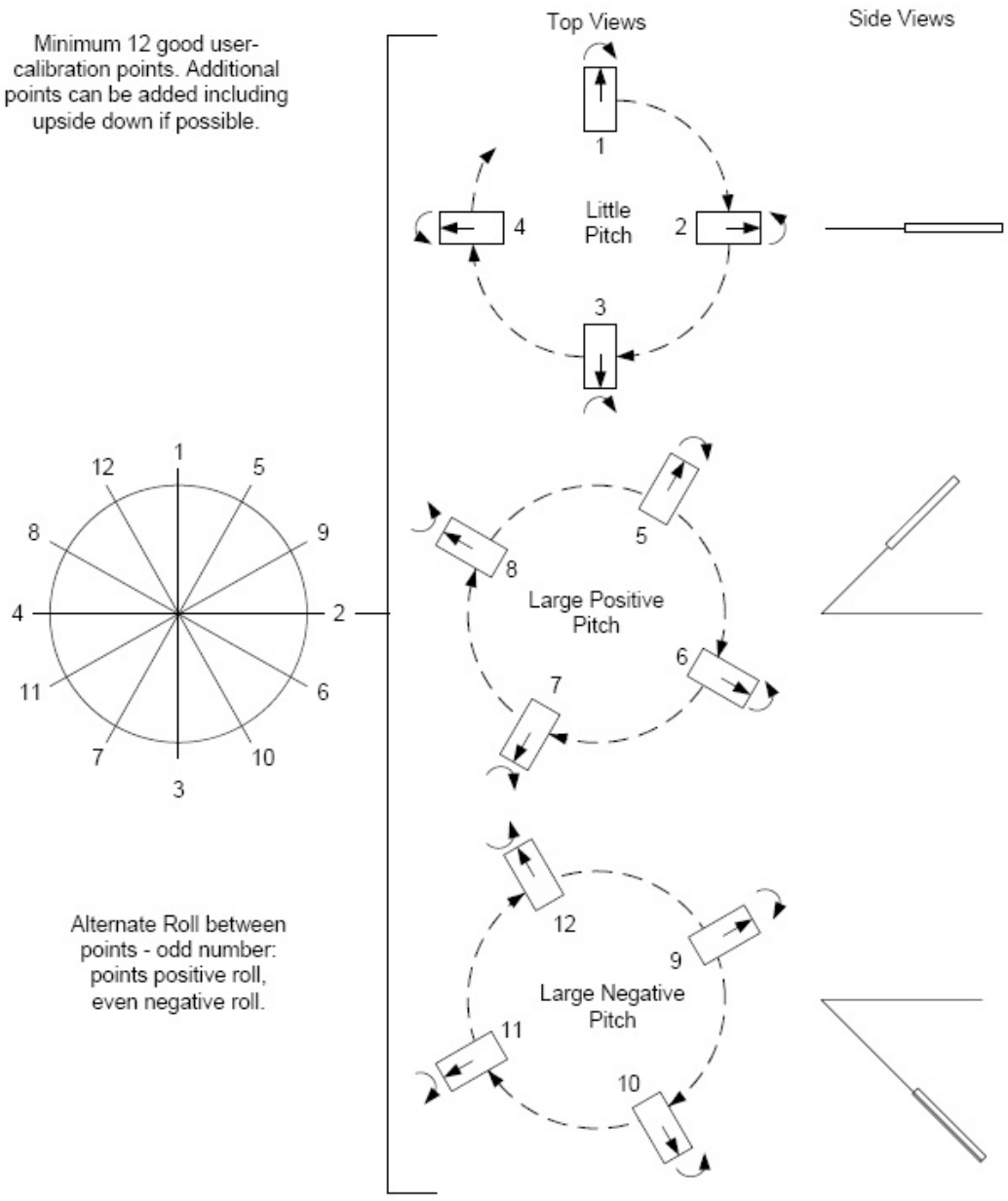


Figure 6-2: Magnetometer 12 Point Calibration

a) Click the <Start> button
b) Hold the module stable and with a slight pitch.
c) Click the <Take Sample> button
d) Rotate the module to the next orientation, and click the <Take Sample> button when the module is stable in the new orientation.
e) Repeat step d until all 12 samples are taken.
f) Click the <Save> button

The Calibration Results window in TCM Studio displays the CalScore, which should be ≤1. If it is not, check the Dist Error and Tilt Error values to see if either is >1. If the Dist Error is >1, this indicates the calibration sample set wasn't evenly distributed and another calibration should be performed with this in mind. If the Tilt Error value is >1, this indicates the calibration sample's tilt range was not sufficient: confirm this by looking at the Tilt Range value.

6.2.2 2D Calibration with 12 Calibration Points

This calibration procedure is used for very low tilt operation (< 5°) where calibrating the module with higher tilts is not practical.

The 2D Calibration method calibrates out hard and soft iron effects in two dimensions only, and in general is effective for operation and calibration in the tilt range of -5° to 5°. The recommended calibration pattern is a circle of evenly spaced points. Results will be optimized if the tilt in the calibration procedure can match the actual tilt experienced when in service. (For example, if the TCM will be restrained to a level plane in service, this means the best results will be obtained if the calibration is exclusively in a plane, where "maximum…tilt" below would be 0°.) PNI recommends 12 to 32 calibration points for 2D Calibration, although 10 calibration points is acceptable but less likely to yield good results.

0° yaw with no tilt
30° yaw with maximum negative tilt (pitch and roll)
60° yaw with no tilt
90° yaw with maximum positive tilt (pitch and roll)
120° yaw with no tilt
150° yaw with maximum negative tilt (pitch and roll)
180° yaw with no tilt
210° yaw with maximum positive tilt (pitch and roll)
240° yaw with no tilt
270° yaw with maximum negative tilt (pitch and roll)
300° yaw with no tilt
330° yaw with maximum positive tilt (pitch and roll)

6.2.3 Hard Iron Only Calibration with 6 Calibration Points

Over time the magnetic distortions around the TCM may change for a variety of reasons. The Hard Iron Only Calibration method allows the user to quickly recalibrate

the module for hard iron effects in three-dimensions, and generally is effective for operation and calibration in the tilt range of 3° or more (45° or more is suggested). The recommended calibration pattern is a circle of alternate tilted, evenly spaced points, with as much tilt variation as expected during use. PNI recommends at least 6 calibration points for a Hard Iron Only Calibration, although 4 calibration points is acceptable but less likely to yield good results.

0° yaw with -45° tilt (pitch and roll)
60° yaw with +45° tilt (pitch and roll)
120° yaw with -45° tilt (pitch and roll)
180° yaw with +45° tilt (pitch and roll)
240° yaw with -45° tilt (pitch and roll)
300° yaw with +45° tilt (pitch and roll)

6.2.4 Limited Tilt Range Calibration with 12 Calibration Points

This procedure is recommended when 45° of tilt isn't feasible, but >5° of tilt is possible. It provides both hard iron and soft iron distortion correction. The recommended calibration pattern is a series of 3 circles of evenly spaced points, with as much tilt variation as expected during use. PNI recommends 12 to 32 calibration points for a Limited Tilt Range Calibration, although 10 calibration points is acceptable but less likely to yield good results.

Module approximately level

0° yaw
90° yaw
180° yaw
270° yaw

Module with at least +5° of tilt (pitch or roll) - more tilt is better

45° yaw
135° yaw
225° yaw
315° yaw

Module with at least -5° of tilt (pitch or roll) - more tilt is better

45° yaw
135° yaw
225° yaw
315° yaw

Note that a similar and acceptable alternative pattern would be to follow the recommended 12 point Full Range Calibration pattern, but substituting the >±45° of pitch

with whatever pitch can be achieved and the ±10° to ±20° or roll with whatever roll can be achieved up to these limits. (See Section 6.2.1)

6.2.5 Accelerometer Only Calibration with 18 Calibration Points

The requirements for a good accelerometer calibration differ from the requirements for a good magnetometer calibration. For instance, a level yaw sweep, no matter how many points are acquired, is effectively only 1 accelerometer calibration point. PNI recommends 18-32 calibration points for accelerometer calibration, although 12 calibration points is acceptable but less likely to yield good results..

Figure 6-3 shows the two basic starting positions for the Accelerometer Only Calibration. Calibration can occur within the user's system or with the module alone. It is not necessary for the module to be placed on a hard surface as shown, but the module must be held still during calibration, and holding it against a hard surface is one method to help ensure this.

Starting with the module as shown on the left in Figure 6-3, rotate the module such that it sits on each of its 6 faces. Take a calibration point on each face.

Starting with the module as shown on the left, rotate it 45° such that it is standing on one of its corners, as shown for the module on the right. The picture shows the module also rotated about its Z axis, but this is only for illustration purposes. Take a calibration point (0°). Now tilt the module back 45° and take another calibration point (+45°), then tilt the module forward 45° and take another calibration point (-45°). Repeat this 3 point calibration process for the module with it resting on each of its 4 corners.

Note that the calibration points can be obtained in any order.

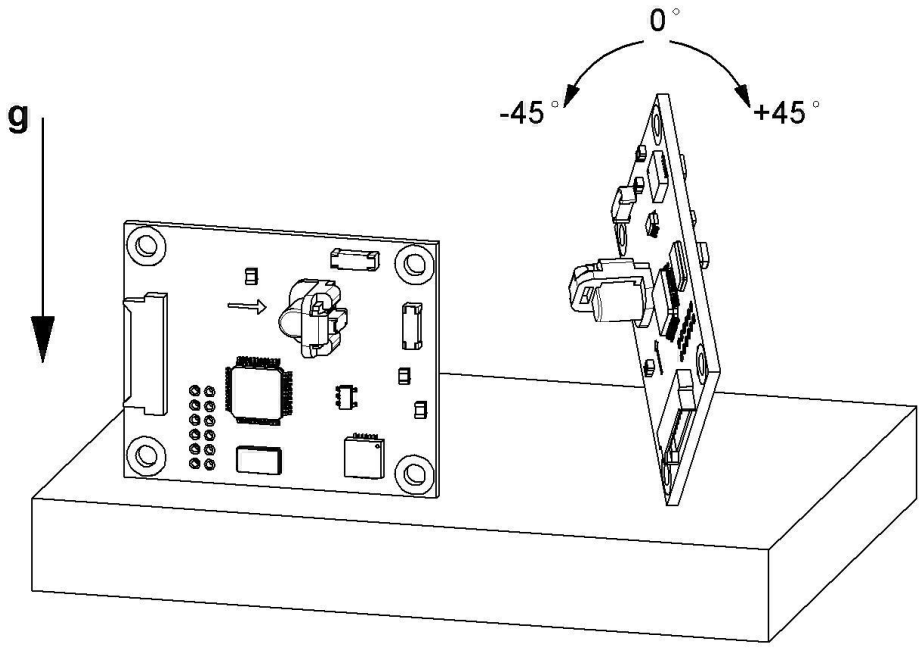


Figure 6-3: Accelerometer Calibration Starting Orientations

6.2.6 Mag and Accel Calibration

The TCM allows for a simultaneous magnetometer and accelerometer calibration. This requires a good calibration pattern, stable measurements (not handheld), and installation in the user's system such that the appropriate local magnetic environment is present. PNI recommends 18 to 32 calibration points for a Mag and Accel Calibration, although 12 calibration points is acceptable but less likely to yield good results. The Accelerometer Only Calibration pattern discussed in Section 6.2.5 will work for a Mag and Accel Calibration. Optimal performance is obtained when all rotations of the cube are performed towards magnetic north to achieve the widest possible magnetic field distribution.

Note that combining calibrations only makes sense if all the host system's magnetic distortions (steel structures or batteries, for instance) are present and fixed relative to the module when calibrating. If the Accelerometer Only Calibration is performed, the user's system distortions are not relevant, which allows the TCM to be removed from the host system in order to perform the Accelerometer Only Calibration.

6.3 Declination Value

Declination, also called magnetic variation, is the difference between true and magnetic north, relative to a point on the earth. It is measured in degrees east or west of true north. Correcting for declination is accomplished by storing the correct declination angle, and then changing the heading reference from magnetic north to true north. Declination angles vary throughout the world, and change very slowly over time. For the greatest possible accuracy, go to the National Geophysical Data Center web page below to get the declination angle based on your latitude and longitude:

http://www.ngdc.noaa.gov/geomagmodels/Declination.jsp

6.4 Other Limitations

The TCM measures the total magnetic field within its vicinity, and this is a combination of the earth's magnetic field and local magnetic sources. The module can compensate for local static magnetic sources that do not exceed the dynamic range of its magnetometers. A magnetic source which is not static can create errors, and it is not possible to compensate for such a dynamic nature. In such cases, moving the TCM away from dynamic magnetic fields is recommended.

7 Operation with RS232 Interface

7.1 Datagram Structure

The data structure for RS232 communication is shown below:

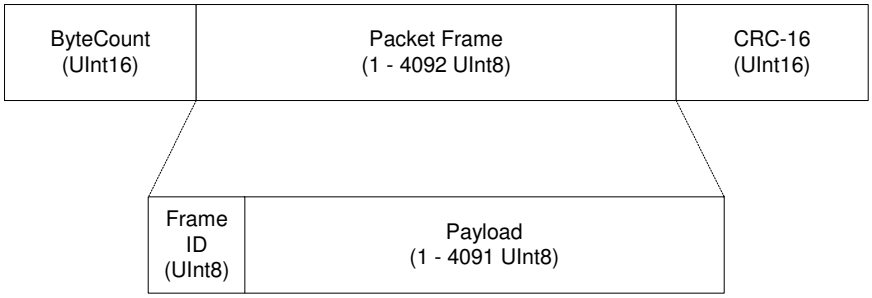


Figure 7-1: Datagram Structure

ByteCount is the total number of bytes in the packet including the CRC-16. CRC-16 is calculated starting from the ByteCount to the last byte of the Packet Frame (see included C function at end of document). The ByteCount and CRC-16 are always transmitted in BIG ENDIAN.

7.2 Parameter Formats

Floating Point

The floating-point based parameters are in the IEEE standard format, ANSI/IEEE Std 754-1985.

64-Bit (double precision floating point)

Shown below is the 64-bit float format in big Endian, in little Endian bytes are in reverse order in 4 byte groups (i.e.: big Endian: ABCDEFGH little Endian: DCBA HGFE).

The value (v) is determined as (if and only if 0 < Exponent < 2047): v = (-1)S * 2(Exponent-1023) * 1.Mantissa

32-Bit (single precision floating point)

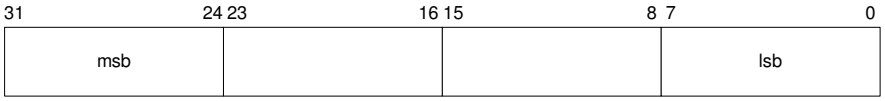
Shown below is the 32-bit float format in big Endian, in little Endian all 4 bytes are in reverse order (LSB first).

The value (v) is determined as (if and only if 0 < Exponent < 255): v = (-1)S * 2(Exponent-127) * 1.Mantissa

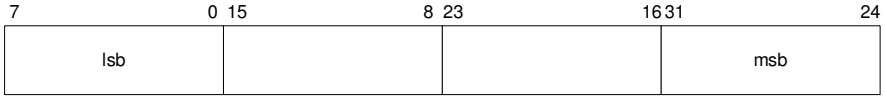
Note: Please refer to ANSI/IEEE Std 754-1985 for more information. It is also recommended that you refer to the compiler you are using on how it implements floating-point formats.

Signed 32-bit Integer (SInt32)

SInt32 based parameters are signed 32 bit numbers (2's compliment). Bit 31 represents the sign of the value (0=positive, 1=negative)



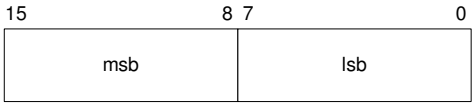
Big Endian



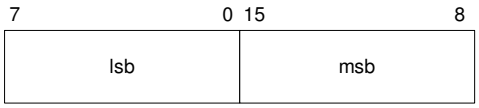
Little Endian

Signed 16-bit Integer (SInt16)

SInt16 based parameters are signed 16 bit numbers (2's compliment). Bit 15 represents the sign of the value (0=positive, 1=negative)



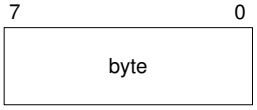
Big Endian



Little Endian

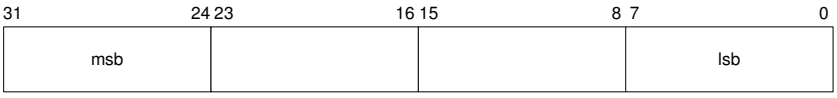
Signed 8-bit Integer (SInt8)

UInt8 based parameters are unsigned 8-bit numbers. Bit 7 represents the sign of the value (0=positive, 1=negative)

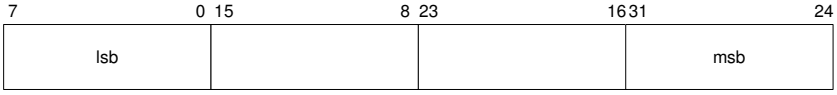


Unsigned 32-bit Integer (UInt32)

UInt32 based parameters are unsigned 32 bit numbers.



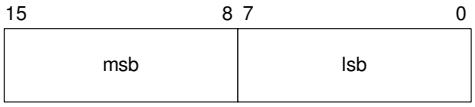
Big Endian



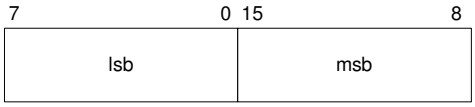
Little Endian

Unsigned 16-bit Integer (UInt16)

UInt16 based parameters are unsigned 16 bit numbers.



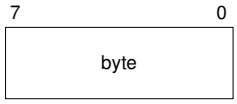
Big Endian



Little Endian

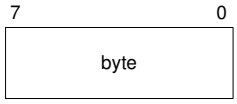
Unsigned 8-bit Integer (UInt8)

UInt8 based parameters are unsigned 8-bit numbers.



Boolean

Boolean is a 1-byte parameter that MUST have the value 0 (FALSE) or 1 (TRUE).



7.3 Commands & Communication Frames

Table 7-1: RS232 Command Set

Frame ID	Command	Description
1	kGetModInfo	Queries the modules type and firmware revision number.
2	kModInfoResp	Response to kGetModInfo
3	kSetDataComponents	Sets the data components to be output.
4	kGetData	Queries the module for data
5	kDataResp	Response to kGetData
6	kSetConfig	Sets internal configurations in the module
7	kGetConfig	Queries the module for the current internal configuration value
8	kConfigResp	Response to kGetConfig
9	kSave	Commands the module to save internal and user calibration
10	kStartCal	Commands the module to start user calibration
11	kStopCal	Commands the module to stop user calibration
12	kSetParam	Sets the FIR filter settings for the magnetometer & accelerometer sensors.
13	kGetParam	Queries for the FIR filter settings for the magnetometer & accelerometer sensors.
14	kParamResp	Contains the FIR filter settings for the magnetometer & accelerometer sensors.
15	kPowerDown	Used to completely power-down the module
16	kSaveDone	Response to kSave
17	kUserCalSampCount	Sent from the module after taking a calibration sample point
18	kUserCalScore	Contains the calibration score
19	kSetConfigDone	Response to kSetConfig
20	kSetParamDone	Response to kSetParam
21	kStartIntervalMode	Commands the module to output data at a fixed interval
22	kStopIntervalMode	Commands the module to stop data output at a fixed interval
23	kPowerUp	Sent after wake up from power down mode
24	kSetAcqParams	Sets the sensor acquisition parameters
25	kGetAcqParams	Queries for the sensor acquisition parameters
26	kAcqParamsDone	Response to kSetAcqParams
27	kAcqParamsResp	Response to kGetAcqParams
28	kPowerDownDone	Response to kPowerDown
29	kFactoryUserCal	Clears user magnetometer calibration coefficients
30	kFactorUserCalDone	Response to kFactoryUserCal
31	kTakeUserCalSample	Commands the module to take a sample during user calibration
36	kFactoryInclCal	Clears user accelerometer calibration coefficients
37	kFactoryInclCalDone	Respond to kFactoryInclCal
46	kSetMode	Sets the mode of operation of the system
47	kSetModeResp	Response to kSetMode
48	kSyncRead	Queries the module for data in Sync Mode

7.3.1 kGetModInfo (frame ID 1 $_d$)

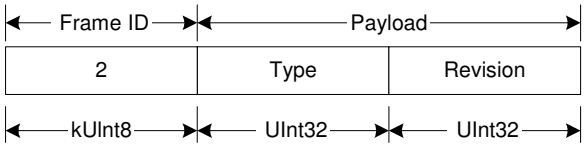
This frame queries the module's type and firmware revision number. The frame has no payload. The complete packet for the kGetModInfo command would be:

0005	01	EFD4

With: 0005 being the byte count
01 kGetModInfo command
EFD4 CRC-16 checksum

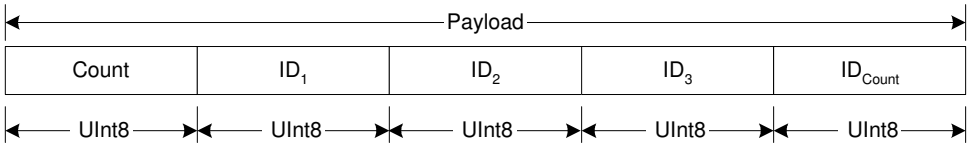
7.3.2 kModInfoResp (frame ID 2 $_d$)

This frame is the response to kGetModInfo frame. The payload contains the module type identifier followed by the firmware revision number.

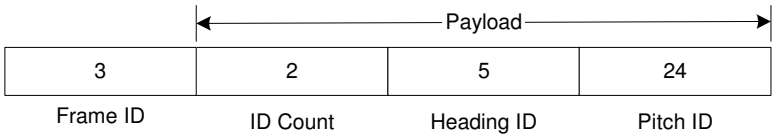


7.3.3 kSetDataComponents (frame ID 3 $_d$)

This frame sets the data components in the module's data output. This is not a query for the module's data (see kGetModInfo). The first byte of the payload indicates the number of data components followed by the data component IDs.



Example: To query the heading and pitch, the payload should contain



When querying for data (kGetData frame), the sequence of the data component output follows the sequence of the data component IDs as set in this frame.

Table 7-2: RS232 Component Identifiers

Component	DataComponentID (decimal)	Format	Units	Range
kHeading	5	Float32	degrees (default) or mils	0.0˚ to 359.9˚
kTemperature	7	Float32	˚ Celsius	-40˚ to 85˚
kDistortion	8	Boolean	True or False	False (Default) = no distortion
kCalStatus	9	Boolean	True or False	False (Default) = not calibrated
kPAligned	21	Float32	G	-1.0 to 1.0
KRAligned	22	Float32	G	-1.0 to 1.0
kIZAligned	23	Float32	G	-1.0 to 1.0
kPAngle	24	Float32	degrees	-90.0˚ to 90.0˚
kRAngle	25	Float32	degrees	-180.0˚ to 180.0˚
KXAligned	27	Float32	µT	
KYAligned	28	Float32	µT	
KZAligned	29	Float32	µT	

Component types are listed below. All are read-only values.

kHeading

Provides compass heading (i.e. yaw or azimuth) output. The units default to degrees, but can be set to mils using kMilOutput

kTemperature

This value is provided by the module's internal temperature sensor. Its value is in °Celsius and has an accuracy of ±3°C.

kDistortion

This flag indicates at least one magnetometer axis reading is beyond ±125 µT.

kCalStatus

This flag indicates the user calibration status. False (default) = not calibrated.

kPAligned, kRAligned & kIZAligned

These values represent Earth's calibrated acceleration vector (G) components. The default values are the factory calibrated values. Up to three (3) sets of values can be stored using kAccelCoeffCopySet (see Section 7.3.6), and this command references whichever set currently is being used.

kPAngle, kRAngle

These outputs provide pitch and roll angles. The pitch range is -90.0˚ to +90.0˚, and the roll range is to -180.0˚ to +180.0˚.

kXAligned, kYAligned, kZAligned

These values represent Earth's calibrated magnetic field (M) vector components. The default values are the factory-calibrated values. Note that up to eight (8) sets of values can be stored using kCoeffCopySet (see Section 7.3.6), and this command references whichever set currently is being used.

7.3.4 kGetData (frame ID 4 d)

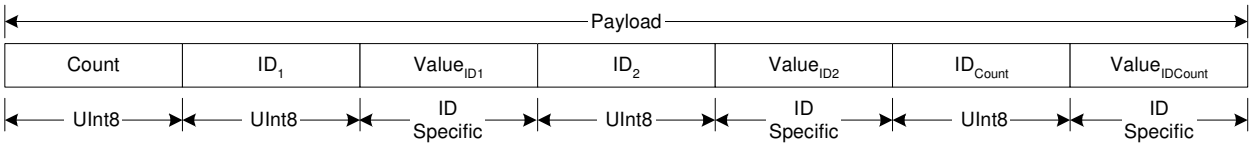
This frame queries the module for data, as established in kSetDataComponents. The frame has no payload. The complete packet for the kGetData command is:

00 05	04	BF71

with: 00 05 the byte count
04 kGetData command
BF71 CRC-16 checksum

7.3.5 kDataResp (frame ID 5 d)

This frame is the response to kGetData frame. The first byte of the payload indicates the number of data components, followed by the data component ID-value pairs. The sequence of the components IDs follows the sequence set in the kSetDataComponents frame.

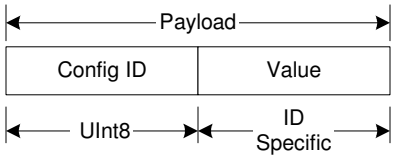


Example: If the response contains the heading and pitch output, the payload would look like

2	5	359.9	24	10.5
ID Count	Heading ID	Heading Output (Float32)	Pitch ID	Pitch Output (Float32)

7.3.6 kSetConfig (frame ID 6 d)

This frame sets internal configurations in the module. The first byte of the payload is the configuration ID followed by a format specific value. These configurations can only be set one at time.



Example: To configure the declination, the payload would look like:

1	10.0
Declination ID	Declination Angle (Float32)

Table 7-3: RS232 Configuration Identifiers

Settings	Config. ID	Format	Values / Range	Default
kDeclination	1	Float32	-180˚ to +180˚	0˚
kTrueNorth	2	Boolean	True or False	False
kBigEndian	6	Boolean	True or False	True
kMountingRef*	10	UInt8	1 = STD 0° 2 = X UP 0° 3 = Y UP 0° 4 = STD 90° 5 = STD 180° 6 = STD 270° 7 = Z UP 0° 8 = X UP 90° 9 = X UP 180° 10 = X UP 270° 11 = Y UP 90° 12 = Y UP 180° 13 = Y UP 270° 14 = Z DOWN 90° 15 = Z DOWN 180° 16 = Z DOWN 270°	1
kUserCalNumPoints	12	UInt32	4 – 32	12
kUserCalAutoSampling	13	Boolean	True or False	True
kBaudRate	14	UInt8	0 – 300 1 – 600 2 – 1200 3 – 1800 4 – 2400 5 – 3600 6 – 4800 7 – 7200 8 – 9600 9 – 14400 10 – 19200 11 – 28800 12 – 38400 13 – 57600 14 - 115200	12
kMilOutput	15	Boolean	True or False	False
kCoeffCopySet	18	UInt32	0 - 7	0
kAccelCoeffCopySet	19	UInt32	0 - 2	0

*Refer to Figure 4-2 for additional information on mounting orientations.

Configuration parameters and settings for kSetConfig:

kDeclination

This sets the declination angle to determine True North heading. Positive declination is easterly declination and negative is westerly declination. This is not applied until kTrueNorth is set to TRUE.

kTrueNorth

Flag to set compass heading output to true north heading by adding the declination angle to the magnetic north heading.

kBigEndian

Flag to set the Endianness of packets

kMountingRef

This sets the reference orientation for the module:

Standard: When selected the module is to be mounted with the main board in a horizontal position (the Z axis magnetic sensor is vertical).

X Sensor Up: When selected the module is to be mounted with the main board in a vertical position (the X axis magnetic sensor is vertical).

Y Sensor Up: When selected the module is to be mounted with the main board in a vertical position (the Y axis magnetic sensor is vertical).

Standard 90 Degrees: When selected the module is to be mounted with the main board in a horizontal position but rotated so the arrow is pointed 90 degrees counterclockwise to the front of the host system.

Standard 180 Degrees: When selected the module is to be mounted with the main board in a horizontal position but rotated so the arrow is pointed 180 degrees counterclockwise to the front of the host system.

Standard 270 Degrees: When selected the module is to be mounted with the main board in a horizontal position but rotated so the arrow is pointed 270 degrees counterclockwise to the front of the host system.

kUserCalNumPoints

The maximum number samples taken during user calibration.

kUserCalAutoSampling

This flag is used during user calibration. If set to TRUE, the module continuously takes calibration sample points until the set number of calibration samples. If set to FALSE, the module waits for kTakeUserCalSample frame to take a sample with the condition that a magnetic field vector component delta is greater than 5 µT from the last sample point.

kBaudRate

Baud rate index value. A power-down power-up cycle is required when changing the baud rate.

kMilOutput

This flag sets the heading, pitch and roll output to mils. By default, kMilOutput is set to FALSE and the heading, pitch and roll output are in degrees. Note that 360 degrees = 6400 mils, such that 1 degree = 17.778 mils or 1 mil = 0.05625 degree.

kCoeffCopySet

This command provides the flexibility to store up to eight (8) sets of magnetometer calibration coefficients in the module. The default is set number 0. To store a set of coefficients, first establish the set number (number 0 to 7) using

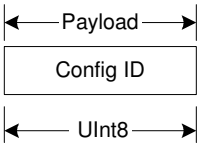
kCoeffCopySet, then perform the magnetometer calibration. The coefficient values will be stored in the defined set number. This feature is useful if the compass will be placed in multiple locations that have different local magnetic field properties.

kAccelCoeffCopySet

This command provides the flexibility to store up to three (3) sets of accelerometer calibration coefficients in the module. The default is set number 0. To store a set of coefficients, first establish the set number (number 0 to 2) using kAccelCoeffCopySet, then perform the accelerometer calibration. The coefficient values will be stored in the defined set number.

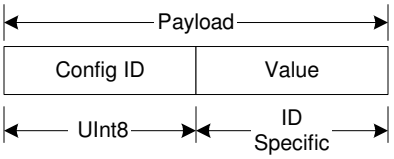
7.3.7 kGetConfig (frame ID 7 d)

This frame queries the module for the current internal configuration value. The payload contains the configuration ID requested.

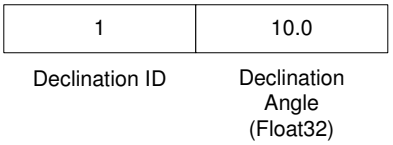


7.3.8 kConfigResp (frame ID 8 d)

This frame is the response to kGetConfig frame. The payload contains the configuration ID and value.



Example: If a request to get the set declination angle, the payload would look like:



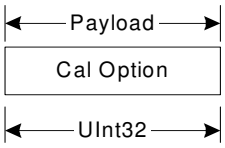
7.3.9 kSave (frame ID 9 d)

This frame commands the module to save internal configurations and user calibration to non-volatile memory. Internal configurations and user calibration is restored on power up. The frame has no payload. This is the ONLY command that causes the module to save information into non-volatile memory.

7.3.10 kStartCal (frame ID 10 d)

This frame commands the module to start user calibration with the current sensor acquisition parameters, internal configurations and FIR filter settings.

Note: The payload needs to be 32 bit (4 byte). If no payload is entered or if less than 4 bytes are entered, the unit will default to the previous calibration method.



Calibration option values:

Calibration option values: 10 = Full Range Calibration (magnetometer only)
20 = 2D Calibration (magnetometer only)
30 = Hard Iron Only Calibration (magnetometer only)
40 = Limited Tilt Range Calibration (magnetometer only)
100 = Accelerometer Only Calibration
110 = Accel and Mag Calibration

Example for a complete sample frame for a 2D Calibration:

00 09 0A 00 00 00 14 5C F9

Heading, pitch and roll information will be output via the kDataResp frame during the calibration process. This feature provides guidance during the calibration regarding calibration sample point coverage. During calibration, in the kDataResp frame, the number of data components is set to be 3 and then followed by the data component ID-value pairs. The sequence of the component IDs are kHeading, kPAngle and kRAngle.

7.3.11 kStopCal (frame ID 11 d)

This frame commands the module to abort the calibration process. The prior calibration results are retained.

7.3.12 kSetParam (frame ID 12 d)

This frame sets the FIR filter settings for the magnetometer and accelerometer sensors. The second byte of the payload indicates the x vector component of either the magnetometer or accelerometer. This is to differentiate whether to apply the filter settings to the magnetometer or accelerometer. The third byte in the payload indicates the number of FIR taps to use then followed by the filter taps. Each tap is a Float64. The maximum number of taps that can be set is 32 and the minimum is 0 (no filtering). Parameter ID should be set to 3.

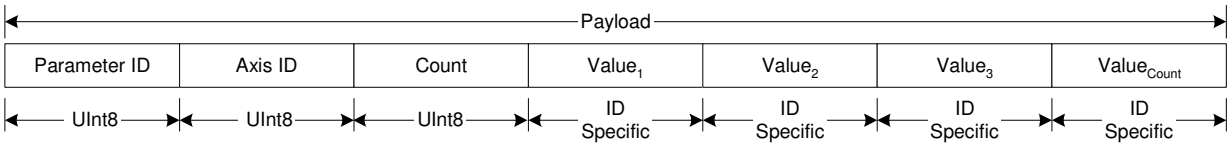
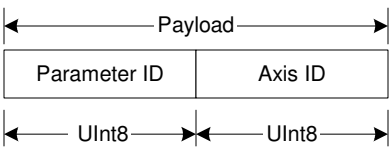


Table 7-4: Recommended FIR Filter Tap Values

Count	4 Tap Filter	8 Tap Filter	16 Tap Filter	32 Tap Filter
1	04.6708657655334e-2	01.9875512449729e-2	07.9724971069144e-3	01.4823725958818e-3
2	04.5329134234467e-1	06.4500864832660e-2	01.2710056429342e-2	02.0737124095482e-3
3	04.5329134234467e-1	01.6637325898141e-1	02.5971390034516e-2	03.2757326624196e-3
4	04.6708657655334e-2	02.4925036373620e-1	04.6451949792704e-2	05.3097803863757e-3
5		02.4925036373620e-1	07.1024151197772e-2	08.3414139286254e-3
6		01.6637325898141e-1	09.5354386848804e-2	01.2456836057785e-2
7		06.4500864832660e-2	01.1484431942626e-1	01.7646051430536e-2
8		01.9875512449729e-2	01.2567124916369e-1	02.3794805168613e-2
9			01.2567124916369e-1	03.0686505921968e-2
10			01.1484431942626e-1	03.8014333463472e-2
11			09.5354386848804e-2	04.5402682509802e-2
12			07.1024151197772e-2	05.2436112653103e-2
13			04.6451949792704e-2	05.8693165018301e-2
14			02.5971390034516e-2	06.3781858267530e-2
15			01.2710056429342e-2	06.7373451424187e-2
16			07.9724971069144e-3	06.9231186101853e-2
17				06.9231186101853e-2
18				06.7373451424187e-2
19				06.3781858267530e-2
20				05.8693165018301e-2
21				05.2436112653103e-2
22				04.5402682509802e-2
23				03.8014333463472e-2
24				03.0686505921968e-2
25				02.3794805168613e-2
26				01.7646051430536e-2
27				01.2456836057785e-2
28				08.3414139286254e-3
29				05.3097803863757e-3
30				03.2757326624196e-3
31				02.0737124095482e-3
32				01.4823725958818e-3

7.3.13 kGetParam (frame ID 13_d)

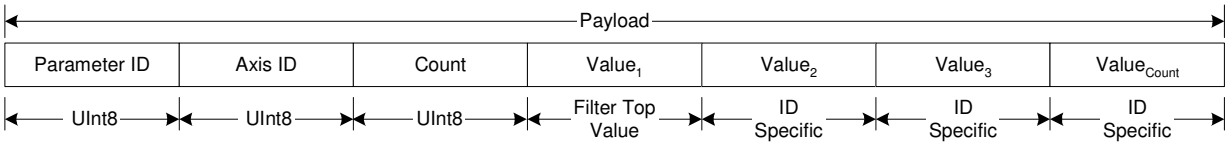
This frame queries the FIR filter settings for the magnetometer and accelerometer sensors. The first byte is the kFIRConfig ID followed by the vector axis ID byte.



Axis IDs:
kXAxis = 1
kYAxis = 2
kZAxis = 3
kPAxis = 4
kRAxis = 5
kIZAxis = 6

7.3.14 kParamResp (frame ID 14 $_d$)

This frame contains the current FIR filter settings for either magnetometer or accelerometer sensors. The second byte of the payload is the vector axis ID, the third byte is the number of filter taps then followed by the filter taps. Each tap is a Float64.

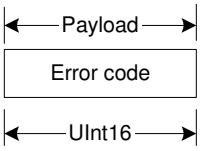


7.3.15 kPowerDown (frame ID 15 $_d$)

This frame is used to completely power-down the module. The frame has no payload. The module will power down all peripherals including the RS-232 driver but the driver chip has the feature to keep the Rx line enabled. Any character sent to the module causes it to exit power down mode. It is recommended to send the byte oxFFh.

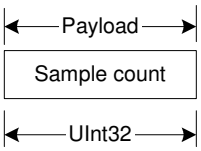
7.3.16 kSaveDone (frame ID 16 $_d$)

This frame is the response to kSave frame. The payload contains a UInt16 error code, 0000h indicates no error, 0001h indicates error when attempting to save data into non-volatile memory.



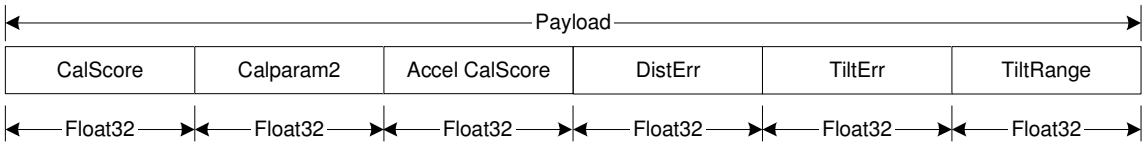
7.3.17 kUserCalSampCount (frame ID 17 $_d$)

This frame is sent from the module after taking a calibration sample point. The payload contains the sample count with the range of 1 to 50



7.3.18 kUserCalScore (frame ID 18 d)

This frame's payload contains the calibration score, which is a series of Float32 values: CalScore, Calparam2,Calparam3,DistErr,TiltErr,TiltRange.



CalScore (Mag CalScore):
Represents the over-riding indicator of the quality of the magnetometer calibration. Acceptable scores will be <1 for full range calibration, <2 for other methods.

Calparam2:
Reserved values for PNI use

Calparam3 (Accel CalScore):
Represents the over-riding indicator of the quality of the accelerometer calibration. An acceptable scores is <1.

DistErr:

Indicates the contribution to the CalScore caused by the quality of the sample point distribution. The score should be <1 and close to 0

TiltErr:
Indicates the contribution to the CalScore caused by tilt or lack thereof. The score takes into account the calibration method. The score should be <1 and close to 0.

TiltRange:
Measured tilt range of sample points. For Full Range Calibration and Hard Iron Only Calibration, this should be close to 180°. For 2D Calibration, this should be ≈2°. For Limited Tilt Range Calibration the value should be as large a possible given the user's constraints.

7.3.19 kSetConfigDone (frame ID 19 d)

This frame is the response to kSetConfig frame. The frame has no payload.

7.3.20 kSetParamDone (frame ID 20 d)

This frame is the response to kSetParam frame. The frame has no payload.

7.3.21 kStartIntervalMode (frame ID 21 $_d$)

The frame commands the module to output data (push mode) at a fixed time interval (See kSetAcqParams). The frame has no payload.

7.3.22 kStopIntervalMode (frame ID 22 $_d$)

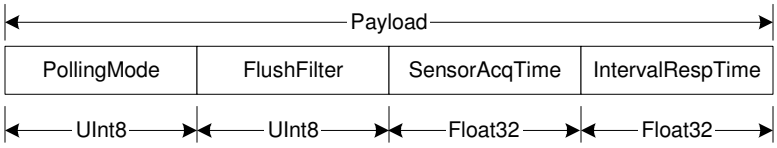
This frame commands the module to stop data output at a fixed time interval. The frame has no payload.

7.3.23 kPowerUp (frame ID 23 $_d$)

This frame is sent from the module after wake up from power down mode. The frame has no payload. Since the module was previously powered down which drives the RS-232 driver TX line low (break signal), it is recommended to disregard the first byte.

7.3.24 kSetAcqParams (frame ID 24 $_d$)

This frame sets the sensor acquisition parameters in the module. The payload should contain the following:



PollingMode:
Flag to set push/poll data output mode. Default is TRUE (poll mode).

FlushFilter:
Flag to set FIR filter flushing every sample. Default is FALSE (no flushing).

SensorAcqTime:
The internal time interval between sensor acquisitions. Default is 0.0 seconds, this means that the module will reacquire immediately right after the last acquisition.

IntervalRespTime:
The time interval the module output data in push mode. Default is 0.0 seconds, this means that the module will push data out immediately after an acquisition cycle.

7.3.25 kGetAcqParams (frame ID 25 $_d$)

This frame queries the unit for acquisition parameters. The frame has no payload.

7.3.26 kAcqParamsDone (frame ID 26 $_d$)

This frame is the response to kSetAcqParams frame. The frame has no payload.

7.3.27 kAcqParamsResp (frame ID 27 $_d$)

This frame is the response to kGetAcqParams frame. The payload should contain the same payload as the kSetAcqParams frame.

7.3.28 kPowerDownDone (frame ID 28 $_d$)

This frame is the response to kPowerDown frame. This indicates that the module successfully received the kPowerDone frame and is in the process of powering down. The frame has no payload.

7.3.29 kFactoryUserCal (frame ID 29 $_d$)

This frame clears the user magnetometer calibration coefficients. The frame has no payload. This frame must be followed by the kSave frame to change in non-volatile memory.

7.3.30 kFactoryUserCalDone (frame ID 30 $_d$)

This frame is the response to kFactoryUserCal frame. The frame has no payload.

7.3.31 kTakeUserCalSample (frame ID 31 $_d$)

This frame commands the module to take a sample during user calibration. The frame has no payload.

7.3.32 kFactoryInclCal (frame ID 36 $_d$)

This frame clears the user accelerometer calibration coefficients. The frame has no payload. This frame must be followed by the kSave frame to change in non-volatile memory.

7.3.33 kFactoryInclCalDone (frame ID 37 $_d$)

This frame is the response to kFactoryInclCal frame. The frame has no payload.

7.3.34 kSetMode (frame ID 46 $_d$)

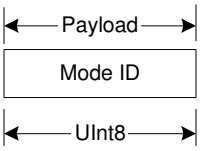
This frame sets the mode of operation of the system. The payload contains the Mode ID requested. If the module is currently in Sync Mode and the user desires to switch back to Normal Mode, an "FF_h" string first must be sent, followed by some minimum delay time prior to sending the kSetMode frame. The minimum delay time is dependent on the baud rate, and for a baud rate equal to or slower than 9600 there is no delay. For baud rates greater than 9600 the minimum delay is equal to:

Minimum delay after sending "FF_h" (in seconds) = 7E-3 – (10/baud rate)

For example, with a baud rate of 38400, the minimum delay after sending "FF_h" is:

Minimum Delay at 38400 baud = 7E-4 – (10/38400) = 4.4E-4 seconds = 440 µs.

Note: When Sync Mode is selected, the TCM will acknowledge the change in mode and immediately trigger the Sync Mode and send a data frame.

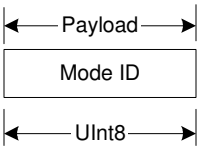


Mode ID: 0: Normal Mode

100: Sync Mode

7.3.35 kSetModeResps (frame ID 47 $_d$)

This frame is the response to kSetMode frame. The payload contains the Mode ID requested.



7.3.36 kSyncRead (frame ID 49 $_d$)

This frame requests a reading from the module when the unit is in Sync Mode. This frame has no payload. The response to this frame is kDataResp, with heading, pitch, and roll set as the sequence of data component IDs.

Prior to sending the kSyncRead frame, the user's system must first send an "FF_h" string which wakes up the system, then wait some minimum delay time before sending the kSyncRead frame. The minimum delay time is dependent on the baud rate, and for a baud rate equal to or slower than 9600 there is no delay. The minimum delay is defined by the following formula:

Minimum Delay after sending "FF_h" (in seconds) = 7E-4 – (10/baud rate)

For example, with a baud rate of 38400, the minimum delay after sending "FF_h" is:

Minimum Delay at 38400 baud = 7E-4 – (10/38400) = 4.4E-4 seconds = 440 µs.

Sync Mode generally is intended for applications in which sampling does not occur frequently. For applications where Sync Mode sampling will be at a frequency of 1 Hz or higher, the user should be aware there is a minimum allowable delay between taking samples. This minimum delay between samples (approximately inverse to the maximum sample rate) varies from 100 msec to 1.06 second and is a function of the number of FIR filter taps, as defined by the following formula:

Minimum Delay between Samples (in seconds) = 0.1 + 0.03*(number of Taps)

7.4 Code Examples

The following example files, CommProtocol.h, CommProtocol.cp, TCM.h and TCM.cp would be used together for proper communication with a TCM module.

NOTE: The following files are not included in the samples code, and would need to be created by the user: SystemSenPort.h; Processes.h, TickGenerator.h.

7.4.1 Header File & CRC-16 Function

```
// type declarations
typedef struct
{
   UInt8 pollingMode, flushFilter;
   Float32 sensorAcqTime, intervalRespTime;
} __attribute__ ((packed)) AcqParams;

typedef struct
{
   Float32 MagCalScore;
   Float32 reserve1;
   Float32 AccelCalScore;
   Float32 DistErr;
   Float32 TiltErr;
   Float32 TiltRange;
} __attribute__ ((packed)) CalScore;

enum
{
   // Frame IDs (Commands)
   kGetModInfo = 1,          // 1
   kModInfoResp,             // 2
   kSetDataComponents,       // 3
   kGetData,                 // 4
   kDataResp,                // 5
   kSetConfig,               // 6
   kGetConfig,               // 7
   kConfigResp,              // 8
   kSave,                    // 9
   kStartCal,                // 10
   kStopCal,                 // 11
   kSetParam,                // 12
   kGetParam,                // 13
   kParamResp,               // 14
   kPowerDown,               // 15
   kSaveDone,                // 16
   kUserCalSampCount,        // 17
   kUserCalScore,            // 18
   kSetConfigDone,           // 19
   kSetParamDone,            // 20
   kStartIntervalMode,       // 21
   kStopIntervalMode,        // 22
   kPowerUp,                 // 23
   kSetAcqParams,            // 24
   kGetAcqParams,            // 25
```

```
kAcqParamsDone,           // 26
kAcqParamsResp,           // 27
kPowerDoneDown,           // 28
kFactoryUserCal,          // 29
kFactoryUserCalDone,      // 30
kTakeUserCalSample,       // 31
kFactoryInclCal = 36,     // 36
kFactoryInclCalDone,      // 37
kSetMode = 46,            // 46
kSetModeDone,             // 47
kSyncRead = 49,           // 49

// Cal Option IDs
kFullRangeCal = 10,            // 10 - type Float32
k2DCal = 20,                   // 20 - type Float32
kHIOnlyCal = 30,               // 30 - type Float32
kLimitedTiltCal = 40,          // 40 - type Float32
kAccelCalOnly = 100,           // 100 - type Float32
kAccelCalwithMag = 110,        // 110 - type Float32

// Param IDs
kFIRConfig = 3,
// 3- AxisID(UInt8)+Count(UInt8)+Value(Float64)+...

// Data Component IDs

kHeading = 5,              // 5 - type Float32
kTemperature = 7,          // 7 - type Float32
kDistortion = 8,           // 8 - type boolean
kPAligned = 21,            // 21 - type Float32
kRAligned,                 // 22 - type Float32
kIZAligned,                // 23 - type Float32
kPAngle,                   // 24 - type Float32
kRAngle,                   // 25 - type Float32
kXAligned = 27,            // 27 - type Float32
kYAligned,                 // 28 - type Float32
kZAligned,                 // 29 - type Float32

// Configuration Parameter IDs
kDeclination = 1,          // 1 - type Float32
kTrueNorth,                // 2 - type boolean
kMountingRef = 10,         // 10 - type UInt8
kUserCalStableCheck,       // 11 - type boolean
kUserCalNumPoints,         // 12 - type UInt32
kUserCalAutoSampling,      // 13 - type boolean
kBaudRate,                 // 14 - UInt8
kMilOutPut = 15,           // 15 - type Boolean
kCoeffCopySet = 18,        // 18 - type UInt32
kAccelCoeffCopySet,        // 19 - type UInt32

// Mounting Reference IDs
kMountedStandard = 1,      // 1
kMountedXUp,               // 2
kMountedYUp,               // 3
kMountedStdPlus90,         // 4
kMountedStdPlus180,        // 5
kMountedStdPlus270,        // 6

// Result IDs
kErrNone = 0,              // 0
kErrSave,                  // 1
```

```
};


// function to calculate CRC-16
UInt16 CRC(void * data, UInt32 len)
{
   UInt8 * dataPtr = (UInt8 *)data;
   UInt32 index = 0;
   // Update the CRC for transmitted and received data using
   // the CCITT 16bit algorithm (X^16 + X^12 + X^5 + 1).
   UInt16 crc = 0;
   while(len--)
   {
         crc = (unsigned char)(crc >> 8) | (crc << 8);
         crc ^= dataPtr[index++];
         crc ^= (unsigned char)(crc & 0xff) >> 4;
         crc ^= (crc << 8) << 4;
         crc ^= ((crc & 0xff) << 4) << 1;
   }
   return crc;
}
```

7.4.2 CommProtocol.h File

Note: This file contains objects used to handle the serial communication with the module. Unfortunately, these files are not available as the program was written on a non-PC computer. The comments in the code should explain what is expected to be sent or received from these functions so that you can write this section for your specific platform. For example, with the TickGenerator.h, you would need to write a routing that generates 10msec ticks.

```
#pragma once

#include "SystemSerPort.h"
#include "Processes.h"


//
//CommHandler is a base class that provides a callback for
//incoming messages.
//
class CommHandler
{
   public:
         // Call back to be implemented in derived class.
         virtual void HandleComm(UInt8 frameType, void * dataPtr =
NULL, UInt16 dataLen = 0) {}
};

//
//  CommProtocol handles the actual serial communication with the
//  module.
//  Process is a base class that provides CommProtocol with
//  cooperative parallel processing.  The Control method will be
//  called by a process manager on a continuous basis.
//
class CommProtocol : public Process
{
   public:
         enum
         {
               // Frame IDs (Commands)
               kGetModInfo = 1,              // 1
               kModInfoResp,                 // 2
               kSetDataComponents,           // 3
               kGetData,                     // 4
               kDataResp,                    //5

               // Data Component IDs
               kHeading = 5,                 // 5 - type Float32
               kTemperature = 7,             // 7 - type Float32
               kPAligned = 21,               // 21 - type Float32
               kRAligned,                    // 22 - type Float32
               kIZAligned,                   // 23 - type Float32
               kPAngle,                      // 24 - type Float32
               kRAngle,                      // 25 - type Float32
         };

         enum
         {
               kBufferSize = 512,
```

```
   // maximum size of our input buffer
                kPacketMinSize = 5
   // minimum size of a serial packet
            };

// SerPort is a serial communication object abstracting
// the hardware implementation
            CommProtocol(CommHandler * handler = NULL, SerPort *
serPort = NULL);

            void Init(UInt32 baud = 38400);

            void SendData(UInt8 frame, void * dataPtr = NULL, UInt32
len = 0);
            void SetBaud(UInt32 baud);

      protected:
            CommHandler * mHandler;
            SerPort * mSerialPort;

            UInt8 mOutData[kBufferSize], mInData[kBufferSize];
            UInt16 mExpectedLen;
            UInt32 mOutLen, mOldInLen, mTime, mStep;

            UInt16 CRC(void * data, UInt32 len);
            void Control();
   };
```

7.4.3 CommProtocol.cp File

```
   #include "CommProtocol.h"

   // import an object that will provide a 10mSec tick count through
   // a function called Ticks()
   #include "TickGenerator.h"

   //  SerPort is an object that controls the physical serial
   // interface.  It handles sending out
   // the characters, and buffers the characters read in until
   // we are ready for them.
   //
   CommProtocol::CommProtocol(CommHandler * handler, SerPort *
serPort)
    : Process("CommProtocol")
   {
      mHandler = handler;
   // store the object that will parse the data when it is fully
   // received
      mSerialPort = serPort;
      Init();
   }

   //  Initialize the serial port and variables that will control
   // this process
   void CommProtocol::Init(UInt32 baud)
   {
      SetBaud(baud);
      mOldInLen = 0;
   // no data previously received
      mStep = 1;
   // goto the first step of our process
   }

   //
   // Put together the frame to send to the module
   //
   void CommProtocol::SendData(UInt8 frameType, void * dataPtr,
UInt32 len)
   {
      UInt8 * data = (UInt8 *)dataPtr;        // the data to send
      UInt32 index = 0;
   // our location in the frame we are putting together
      UInt16 crc;
   // the CRC to add to the end of the packet
      UInt16 count;
   // the total length the packet will be

      count = (UInt16)len + kPacketMinSize;

   // exit without sending if there is too much data to fit
   // inside our packet
      if(len > kBufferSize - kPacketMinSize) return;

   // Store the total len of the packet including the len bytes
   // (2), the frame ID (1),
   // the data (len), and the crc (2).  If no data is sent, the
   // min len is 5
```

```
   mOutData[index++] = count >> 8;
   mOutData[index++] = count & 0xFF;

   // store the frame ID
   mOutData[index++] = frameType ;

   // copy the data to be sent
   while(len--) mOutData[index++] = *data++;

   // compute and add the crc
   crc = CRC(mOutData, index);
   mOutData[index++] = crc >> 8 ;
   mOutData[index++] = crc & 0xFF ;

   // Write block will copy and send the data out the serial port
   mSerialPort->WriteBlock(mOutData, index);
}



//
// Call the functions in serial port necessary to change the
// baud rate
//
void CommProtocol::SetBaud(UInt32 baud)
{
   mSerialPort->SetBaudRate(baud);
   mSerialPort->InClear();
// clear any data that was already waiting in the buffer
}

//
// Update the CRC for transmitted and received data using the
// CCITT 16bit algorithm (X^16 + X^12 + X^5 + 1).
//

UInt16 CommProtocol::CRC(void * data, UInt32 len)
{
   UInt8 * dataPtr = (UInt8 *)data;
   UInt32 index = 0;

   UInt16 crc = 0;
   while(len--)
   {
         crc = (unsigned char)(crc >> 8) | (crc << 8);
         crc ^= dataPtr[index++];
         crc ^= (unsigned char)(crc & 0xff) >> 4;
         crc ^= (crc << 8) << 4;
         crc ^= ((crc & 0xff) << 4) << 1;
   }
   return crc;
}

//
//  This is called each time this process gets a turn to execute.
//
void CommProtocol::Control()
{
// InLen returns the number of bytes in the input buffer of
//the serial object that are available for us to read.
   UInt32 inLen = mSerialPort->InLen();
```

```
      switch(mStep)
      {
            case 1:
            {
   // wait for length bytes to be received by the serial object
                  if(inLen >= 2)
                  {
   // Read block will return the number of requested (or available)
   // bytes that are in the serial objects input buffer.
   // read the byte count
                        mSerialPort->ReadBlock(mInData, 2);

   // byte count is ALWAYS transmitted in big endian, copy byte
   // count to mExpectedLen to native endianess
                        mExpectedLen = (mInData[0] << 8) |
mInData[1];

   // Ticks is a timer function.  1 tick = 10msec.
   // wait up to 1/2s for the complete frame (mExpectedLen) to be
   // received
                        mTime = Ticks() + 50 ;
                        mStep++ ;
   // goto the next step in the process
                  }
                  break ;
            }

            case 2:
            {
                  // wait for msg complete or timeout
                  if(inLen >= mExpectedLen - 2)
                  {
                        UInt16 crc, crcReceived;
   // calculated and received crcs.

   // Read block will return the number of
   // requested (or available) bytes that are in the
   // serial objects input buffer.
                        mSerialPort->ReadBlock(&mInData[2],
mExpectedLen - 2);
   // in CRC verification, don't include the CRC in the
recalculation (-2)
                        crc = CRC(mInData, mExpectedLen - 2);
   // CRC is also ALWAYS transmitted in big endian
                        crcReceived = (mInData[mExpectedLen - 2] <<
8) | mInData[mExpectedLen - 1] ;

                        if(crc == crcReceived)
                        {
   // the crc is correct, so pass the frame up for processing.
                              if(mHandler) mHandler-
>HandleComm(mInData[2], &mInData[3], mExpectedLen - kPacketMinSize);
                        }
                        else
                        {
   // crc's don't match so clear everything that is currently in the
   // input buffer since the data is not reliable.
                              mSerialPort->InClear();
                        }
```

```
// go back to looking for the length bytes.
                    mStep = 1 ;
                }
                else
                {
// Ticks is a timer function.  1 tick = 10msec.
                    if(Ticks() > mTime)
                    {
// Corrupted message.  We did not get the length we were
// expecting within 1/2sec of receiving the length bytes.  Clear
// everything in the input buffer since the data is unreliable
                        mSerialPort->InClear();
                        mStep = 1 ;
// Look for the next length bytes
                    }
                }
                break ;
            }

            default:
                break ;
    }
}
```

7.4.4 TCM.h File

Note: This applies to the TCM3, TCM5, TCM5LT, and TCM.

```
#pragma once

#include "Processes.h"
#include "CommProtocol.h"


//
//  This file contains the object providing communication to the
// TCM.  It will set up the module and parse packets received
//  Process is a base class that provides TCM with cooperative
// parallel processing.  The Control method will be
//  called by a process manager on a continuous basis.
//
class TCM : public Process, public CommHandler
{
   public:
         TCM(SerPort * serPort);
         ~TCM();

   protected:
         CommProtocol * mComm;

         UInt32 mStep, mTime, mResponseTime;

         void HandleComm(UInt8 frameType, void * dataPtr = NULL,
UInt16 dataLen = 0);
         void SendComm(UInt8 frameType, void * dataPtr = NULL,
UInt16 dataLen = 0);

         void Control();
};
```

7.4.5 TCM.cp File

Note: This applies to the TCM3, TCM5, TCM5LT, and TCM.

```
#include "TCM.h"
#include "TickGenerator.h"

const UInt8 kDataCount = 4;
// We will be requesting 4 componets (Heading, pitch, roll,
// temperature)
//
//  This object polls the TCM module once a second for
// heading, pitch, roll and temperature.
//

TCM::TCM(SerPort * serPort)
 : Process("TCM")
{
// Let the CommProtocol know this object will handle any
// serial data returned by the module
   mComm = new CommProtocol(this, serPort);

   mTime = 0;
   mStep = 1;
}

TCM::~TCM()
{
}

//
// Called by the CommProtocol object when a frame is completely
// received
//
void TCM::HandleComm(UInt8 frameType, void * dataPtr, UInt16
dataLen)
{
   UInt8 * data = (UInt8 *)dataPtr;

   switch(frameType)
   {
         case CommProtocol::kDataResp:
         {
// Parse the data response
            UInt8 count = data[0];
// The number of data elements returned
            UInt32 pntr = 1;
// Used to retrieve the returned elements

   // The data elements we requested
            Float32 heading, pitch, roll, temperature;

            if(count != kDataCount)
            {
   // Message is a function that displays a C formatted string
   // (similar to printf)
                  Message("Received %u data elements instead of
the %u requested\r\n", (UInt16)count,
                   (UInt16)kDataCount);
```

```
                        return;
                    }

      // loop through and collect the elements
                    while(count)
                    {
      // The elements are received as {type (ie. kHeading), data}
                        switch(data[pntr++])
      // read the type and go to the first byte of the data
                        {
      // Only handling the 4 elements we are looking for
                            case CommProtocol::kHeading:
                            {
      // Move(source, destination, size (bytes)).  Move copies the
      // specified number of bytes from the source pointer to the
      // destination pointer.  Store the heading.
                                Move(&(data[pntr]), &heading,
sizeof(heading));

      // increase the pointer to point to the next data element type
                                pntr += sizeof(heading);
                                break;
                            }

                            case CommProtocol::kPAngle:
                            {
      // Move(source, destination, size (bytes)).  Move copies the
      // specified number of bytes from the source pointer to the
      // destination pointer.  Store the pitch.
                                Move(&(data[pntr]), &pitch,
sizeof(pitch));

      // increase the pointer to point to the next data element type
                                pntr += sizeof(pitch);
                                break;
                            }

                            case CommProtocol::kRAngle:
                            {
      // Move(source, destination, size (bytes)).  Move copies the
      // specified number of bytes from the source pointer to the
      // destination pointer.  Store the roll.
                                Move(&(data[pntr]), &roll,
sizeof(roll));

      // increase the pointer to point to the next data element type
                                pntr += sizeof(roll);
                                break;
                            }

                            case CommProtocol::kTemperature:
                            {
      // Move(source, destination, size (bytes)).  Move copies the
      // specified number of bytes from the source pointer to the
      // destination pointer.  Store the heading.
                                Move(&(data[pntr]), &temperature,
sizeof(temperature));

      // increase the pointer to point to the next data element type
                                pntr += sizeof(temperature);
                                break;
```

```
                              }

                              default:
      // Message is a function that displays a formatted string
      // (similar to printf)
                                    Message("Unknown type: %02X\r\n",
data[pntr - 1]);
      // unknown data type, so size is unknown, so skip everything
                                    return;
                                    break;
                        }

                        count--;
      // One less element to read in
                  }

      // Message is a function that displays a formatted string
      // (similar to printf)
                  Message("Heading: %f, Pitch: %f, Roll: %f,
Temperature: %f\r\n", heading, pitch, roll,
                   temperature);
                  mStep--;
      // send next data request
                  break;
            }

            default:
            {
      // Message is a function that displays a formatted string
      // (similar to printf)
                  Message("Unknown frame %02X received\r\n",
(UInt16)frameType);
                  break;
            }
      }
   }

   //
   // Have the CommProtocol build and send the frame to the module.
   //
   void TCM::SendComm(UInt8 frameType, void * dataPtr, UInt16
dataLen)
   {
      if(mComm) mComm->SendData(frameType, dataPtr, dataLen);
   // Ticks is a timer function.  1 tick = 10msec.
      mResponseTime = Ticks() + 300;          // Expect a response
within 3 seconds
   }
   //
   //  This is called each time this process gets a turn to execute.
   //
   void TCM::Control()
   {
      switch(mStep)
      {
            case 1:
            {
                  UInt8 pkt[kDataCount + 1];
   // the compents we are requesting, preceded by the number of
   // components being requested
```

```
                pkt[0] = kDataCount;
                pkt[1] = CommProtocol::kHeading;
                pkt[2] = CommProtocol::kPAngle;
                pkt[3] = CommProtocol::kRAngle;
                pkt[4] = CommProtocol::kTemperature;

                SendComm(CommProtocol::kSetDataComponents, pkt,
kDataCount + 1);

      // Ticks is a timer function.  1 tick = 10msec.
                mTime = Ticks() + 100;
   // Taking a sample in 1s.
                mStep++;
   // go to next step of process
                break;
          }

          case 2:
          {
   // Ticks is a timer function.  1 tick = 10msec.
                if(Ticks() > mTime)
                {
   // tell the module to take a sample
                      SendComm(CommProtocol::kGetData);
                      mTime = Ticks() + 100; // take a sample every
second
                      mStep++;
                }
                break;
          }

          case 3:
          {
   // Ticks is a timer function.  1 tick = 10msec.
                if(Ticks() > mResponseTime)
                {
                      Message("No response from the module.  Check
connection and try again\r\n");
                      mStep = 0;
                }
                break;
          }

          default:
                break;
      }
   }
```